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Attorneys for Defendant
WI-LAN, INC.

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

SAN FRANCISCO DIVISION

MARVELL SEMICONDUCTOR INC., a California corporation, Plaintiff, v. WI-LAN, INC., a Canadian Corporation, Defendant.	No. C 07-05626 SI **DECLARATION OF KEVIN L. BURGESS IN SUPPORT OF WI-LAN, INC.'S MOTION TO DISMISS MARVELL SEMICONDUCTOR INC.'S SUIT FOR DECLARATORY RELIEF** Hearing Date: May 23, 2008 Location: Courtroom 10, 19th Floor Time: 9:00 a.m. Honorable Judge Illston

I, KEVIN L. BURGESS, hereby declare as follows:

1. I am an attorney who has *pro hac vice* admission to this Court. I am an associate with McKool Smith P.C., counsel for Wi-LAN, Inc. in this matter. My business address is 300 West 6th Street, Suite 1700, Austin, TX 78701. I have personal knowledge of the facts stated in this declaration, and if called upon to do so, could and would competently testify thereto.

2. Attached as Exhibit A is a true and correct copy of a letter that was executed and sent to counsel for Marvell Semiconductor Inc. on March 28, 2008, "unconditionally agree[ing] not to sue Marvell Semiconductor, Inc. and its customers for patent infringement of any claim of United States Patent Nos. 6,192,068, 6,320,897, and RE37,802, based upon Marvell's PXA90 family of chipsets as it exists today or has existed in the past."

3. Attached as Exhibit B is a true and correct copy of the *Wi-LAN, Inc. v. Westell Techs., Inc.* Complaint.

4. Attached as Exhibit C is a true and correct copy of the *Wi-LAN, Inc. v. Acer, Inc.* Complaint.

5. Attached as Exhibit D is a true and correct copy of Marvell's Answer and Counterclaims to the *Wi-LAN, Inc. v. Westell Techs., Inc.* Complaint.

6. Attached as Exhibit E is a true and correct copy of Marvell's Answer and Counterclaims to the *Wi-LAN, Inc. v. Acer, Inc.* Complaint.

I declare under penalty of perjury under the laws of the United States and the State of California that the foregoing is true and correct. Executed on April 3, 2008 in Austin, Texas.

By: /s/ Kevin L. Burgess
Kevin L. Burgess

I, KEVIN L. BURGESS, hereby declare as follows:

1. I am an attorney who has *pro hac vice* admission to this Court. I am an associate with McKool Smith P.C., counsel for Wi-LAN, Inc. in this matter. My business address is 300 West 6th Street, Suite 1700, Austin, TX 78701. I have personal knowledge of the facts stated in this declaration, and if called upon to do so, could and would competently testify thereto.

2. Attached as Exhibit A is a true and correct copy of a letter that was executed and sent to counsel for Marvell Semiconductor Inc. on March 28, 2008, "unconditionally agree[ing] not to sue Marvell Semiconductor, Inc. and its customers for patent infringement of any claim of United States Patent Nos. 6,192,068, 6,320,897, and RE37,802, based upon Marvell's PXA90 family of chipsets as it exists today or has existed in the past."

3. Attached as Exhibit B is a true and correct copy of the *Wi-LAN, Inc. v. Westell Techs., Inc.* Complaint.

4. Attached as Exhibit C is a true and correct copy of the *Wi-LAN, Inc. v. Acer, Inc.* Complaint.

5. Attached as Exhibit D is a true and correct copy of Marvell's Answer and Counterclaims to the *Wi-LAN, Inc. v. Westell Techs., Inc.* Complaint.

6. Attached as Exhibit E is a true and correct copy of Marvell's Answer and Counterclaims to the *Wi-LAN, Inc. v. Acer, Inc.* Complaint.

I declare under penalty of perjury under the laws of the United States and the State of California that the foregoing is true and correct. Executed on April 3, 2008 in Austin, Texas.

By: Kevin L. Burgess /JEF
Kevin L. Burgess

MCKOOL SMITH

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March 28, 2008

CONFIDENTIAL SETTLEMENT COMMUNICATION
PURSUANT TO F.R.E. 408

VIA FACSIMILE AND E-MAIL

Roger D. Taylor
Finnegan, Henderson, Farabow, Garrett & Dunner, LLP
303 Peachtree Street, N.E.
3500 SunTrust Plaza
Atlanta, GA 30064
404-653-6480
fax 404-653-6444

Re: Case No. C 07-05626 SI; *Marvell Semiconductor, Inc. v. Wi-LAN, Inc.*

Dear Roger:

By way of this letter, to resolve Civil Action 3:07-05262 SI, Wi-LAN, Inc. hereby unconditionally agrees not to sue Marvell Semiconductor, Inc. and its customers for patent infringement of any claim of United States Patent Nos. 6,192,068, 6,320,897, and RE37,802, based upon Marvell's PXA90x family of chipsets as it exists today or has existed in the past.

Under the Federal Circuit's decision in *Super Sack Mfg. v. Chase Packaging Corp.*, 57 F.3d 1054 (Fed. Cir. 1995) and Judge Illston's decisions in *Crossbow Tech., Inc. v. YH Tech.*, No. C 03-04360 SI, 2007 U.S. Dist. LEXIS 8028 (N.D. Cal. Jan. 22, 2007) and *Crossbow Tech., Inc. v. YH Tech.*, No. C 03-04360 SI, 2007 U.S. Dist. LEXIS 65646 (N.D. Cal. Aug. 21, 2007), declaratory judgment jurisdiction no longer exists, and Marvell's suit for declaratory relief with respect to the '068, '897, and '802 patents must be dismissed.

Please let me know as soon as possible whether Marvell agrees to dismiss its claims with respect to the '068, '897, and '802 patents.

Sincerely,

Kevin Burgess

Kevin Burgess w/ PERMISSION John Campbell

Austin 42280v3

UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

WI-LAN INC., Plaintiff, v. WESTELL TECHNOLOGIES, INC., NETGEAR, INC., 2WIRE, INC., D-LINK SYSTEMS, INC., D-LINK CORPORATION, BELKIN INTERNATIONAL, INC., BUFFALO TECHNOLOGY (USA), INC., MELCO HOLDINGS INC., BROADCOM CORPORATION, ATHEROS COMMUNICATIONS, INC, MARVELL SEMICONDUCTOR, INC., TEXAS INSTRUMENTS, INCORPORATED, INFINEON TECHNOLOGIES NORTH AMERICA CORPORATION, INFINEON TECHNOLOGIES AG, INTEL CORPORATION, BEST BUY CO., INC., and CIRCUIT CITY STORES, INC. Defendants.	§ § § § § § § § § § § § § § § § § § § §	Civil Action No. 2-07CV-474 DF JURY TRIAL REQUESTED

ORIGINAL COMPLAINT

Plaintiff Wi-LAN Inc. ("Wi-LAN") files this Original Complaint for patent infringement against Defendants Westell Technologies, Inc. (" Westell"), NETGEAR, Inc. ("NETGEAR"), 2Wire, Inc. ("2Wire"), D-Link Systems, Inc. and D-Link Corporation ("D-Link"), Belkin International, Inc. ("Belkin"), Buffalo Technology (USA), Inc. and Melco Holdings Inc. ("Buffalo") (collectively the "Defendant Suppliers"), Broadcom Corporation ("Broadcom"), Atheros Communications, Inc. ("Atheros"), Marvell Semiconductor, Inc. ("Marvell"), Texas Instruments, Incorporated ("Texas Instruments"), Infineon Technologies North America Corporation and Infineon

Technologies AG ("Infineon"), Intel Corporation ("Intel"), Best Buy Co., Inc. ("Best Buy"), and Circuit City Stores, Inc. ("Circuit City") for infringement of U.S. Patent No. 5,282,222 (the "'222 Patent"), U.S. Patent No. RE37,802 (the "'802 Patent"), and U.S. Patent No. 5,956,323 (the "'323 Patent) (collectively, the "Patents-in-Suit") pursuant to 35 U.S.C. § 271. Copies of the Patents-in-Suit are attached as Exhibits A, B, and C.

PARTIES

1. Plaintiff Wi-LAN Inc. is a corporation existing under the laws of Canada with its principal place of business at 11 Holland Ave., Suite 608, Ottawa, Ontario, Canada.

2. Upon information and belief, Defendant Westell is a Delaware Corporation with its principal place of business at 750 N. Commons Dr., Aurora, IL 60504. Westell manufactures for sale and/or sells wireless products compliant with the IEEE 802.11 standards and Asymmetric Digital Subscriber Line ("ADSL") products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of Texas. Westell may be served with process by serving its registered agent, Melvin J. Simon at 4343 Commerce Court, Suite 616, Lisle, Illinois 60532.

3. Upon information and belief, Defendant NETGEAR is a Delaware Corporation with its principal place of business at 4500 Great American Pkwy., Santa Clara, CA 95054. NETGEAR manufactures for sale and/or sells wireless products compliant with the IEEE 802.11 standards and ADSL products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of

Texas. NETGEAR may be served with process by serving its registered agent, CT Corporation System at 818 West Seventh Street, Los Angeles, California 90017.

4. Upon information and belief, Defendant 2Wire is a Delaware Corporation with its principal place of business at 1704 Automation Pkwy., San Jose, CA 95131. 2Wire manufactures for sale and/or sells wireless products compliant with the IEEE 802.11 standards and ADSL products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of Texas. 2Wire may be served with process by serving its registered agent, National Registered Agents, Inc. at 16055 Space Center, Suite 235, Houston, Texas 77062.

5. Upon information and belief, Defendant D-Link Systems, Inc. is a California Corporation with its principal place of business at 17595 Mt. Hermann St., Fountain Valley, CA 92708. Upon information and belief, Defendant D-Link Corporation is a Taiwanese Corporation with its principal place of business at 4F, No. 289, Sinhu 3rd Rd., Neihu District, Taipei City, Taiwan. D-Link manufactures for sale and/or sells wireless products compliant with the IEEE 802.11 standards and ADSL products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of Texas. Upon information and belief, Defendants D-Link Systems, Inc. and D-Link Corporation are commonly owned by the same corporate entity and are alter egos and/or agents of one another. D-Link may be served with process by serving its registered agent, Nancy Lemm at 17595 Mt. Hermann Street, Fountain Valley, California 92708.

6. Upon information and belief, Defendant Belkin (formerly Belkin Corporation) is a Delaware Corporation with its principal place of business at 501 W.

Walnut St., Compton, CA 90220. Belkin manufactures for sale and/or sells wireless products compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Belkin may be served with process by serving its registered agent, National Registered Agents, Inc. at 2030 Main Street, Suite 1030, Irvine, California 92614.

7. Upon information and belief, Defendant Buffalo Technology (USA), Inc. is a Delaware Corporation with its principal place of business at 11100 Metric Blvd., Suite 750, Austin, TX 78758. Upon information and belief, Defendant Melco Holdings Inc. is a Japanese Corporation with its principal place of business at Kamiya Bldg., 11-50, Ohsu 4-chome, Naka-ku, Nagoya, Aichi Prefecture, Japan. Buffalo manufactures for sale and/or sells wireless products compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Upon information and belief, Defendants Buffalo Technology (USA), Inc. and Melco Holdings Inc. are commonly owned by the same corporate entity and are alter egos and/or agents of one another. Buffalo may be served with process by serving its registered agent, Makoto Maki at 4030 W. Braker Lane, Suite 120, Austin, Texas 78759.

8. Upon information and belief, Defendant Broadcom is a California Corporation with its principal place of business at 5300 California Ave., Irvine, CA 92617. Broadcom manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant Suppliers' ADSL products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of Texas. Broadcom may be served with process by

serving its registered agent, National Registered Agents, Inc. at 2030 Main Street, Suite 1030, Irvine, California 92614.

9. Upon information and belief, Defendant Atheros is a Delaware Corporation with its principal place of business at 5480 Great America Pkwy., Santa Clara, CA 95054. Atheros manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Atheros may be served with process by serving its registered agent, LexisNexis Document Solutions, Inc. at 701 Brazos Street, Suite 1050, Austin, Texas 78701.

10. Upon information and belief, Defendant Marvell Semiconductor, Inc. is a California Corporation with its principal place of business at 5488 Marvell Ln., Santa Clara, CA 95054-3606. Marvell manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Marvell may be served with process by serving its registered agent, CT Corporation System, at 818 West Seventh Street, Los Angeles, California 90017.

11. Upon information and belief, Defendant Texas Instruments is a Delaware Corporation with its principal place of business at 12500 TI Blvd., Dallas, TX 75266-4136. Texas Instruments manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant

Suppliers' ADSL products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of Texas. Texas Instruments may be served with process by serving its registered agent, Joseph F. Huback at 7839 Churchill Way, MS3999, Dallas, Texas 75251.

12. Upon information and belief, Defendant Infineon Technologies North America Corporation is a Delaware Corporation with its principal place of business at 3000 Centregreen Way, Cary, NC 27513-5759. Upon information and belief, Defendant Infineon Technologies AG is a German Corporation with its principal place of business at Am Campeon 1-12, Neubiberg 85579 Germany. Infineon manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant Suppliers' ADSL products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of Texas. Upon information and belief, Defendants Infineon Technologies North America Corporation and Infineon Technologies AG are commonly owned by the same corporate entity and are alter egos and/or agents of one another. Infineon may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

13. Upon information and belief, Defendant Intel is a Delaware Corporation with its principal place of business at 2200 Mission College Blvd., Santa Clara, CA 95054-1549. Intel manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards in the United States and, more

particularly, in the Eastern District of Texas. Intel may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

14. Upon information and belief, Defendant Best Buy is a Minnesota Corporation with its principal place of business at 7601 Penn Ave. S., Richfield, MN 55423. Best Buy offers for sale and/or sells one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant Suppliers' ADSL products compliant with the ITU G.992 standards in the United States and, more particularly, in the Eastern District of Texas. Best Buy may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

15. Upon information and belief, Defendant Circuit City is a Virginia Corporation with its principal place of business at 9950 Mayland Dr., Richmond, VA 23233. Circuit City offers for sale and/or sells one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Circuit City may be served with process by serving its registered agent, Prentice Hall Corporation System, Inc. at 701 Brazos Street, Suite 1050, Austin, Texas 78701.

JURISDICTION AND VENUE

16. This is an action for patent infringement under the Patent Laws of the United States, 35 U.S.C. § 271.

17. This Court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1331 and 1338(a).

18. This Court has personal jurisdiction over each Defendant. Each Defendant has conducted and does conduct business within the State of Texas. Each Defendant, directly or through intermediaries (including distributors, retailers, and others), ships, distributes, offers for sale, sells, imports and advertises (including the provision of an interactive web page) its products in the United States, the State of Texas, and the Eastern District of Texas. Each Defendant has purposefully and voluntarily placed one or more of its infringing products, as described below, into the stream of commerce with the expectation that they will be purchased by consumers in the Eastern District of Texas. These infringing products have been and continue to be purchased by consumers in the Eastern District of Texas. Each Defendant has committed the tort of patent infringement within the State of Texas, and particularly, within the Eastern District of Texas.

19. Venue is proper in this Court pursuant to 28 U.S.C. §§ 1391 and 1400(b).

COUNT I: PATENT INFRINGEMENT

20. On January 25, 1994, the United States Patent and Trademark Office ("USPTO") duly and legally issued the '222 Patent, entitled "Method and Apparatus for Multiple Access Between Transceivers in Wireless Communications Using OFDM Spread Spectrum" after a full and fair examination. Wi-LAN is the assignee of all rights, title, and interest in and to the '222 Patent and possesses all rights of recovery under the '222 Patent, including the right to recover damages for past infringement.

21. On July 23, 2002, the USPTO duly and legally issued the '802 Patent, entitled "Multicode Direct Sequence Spread Spectrum" after a full and fair examination. Wi-LAN is the assignee of all rights, title, and interest in and to the '802 Patent and possesses all rights of recovery under the '802 Patent, including the right to recover damages for past infringement.

22. On September 21, 1999, the USPTO duly and legally issued the '323 Patent, entitled "Power Conservation for POTS and Modulated Data Transmission" after a full and fair examination. Wi-LAN is the assignee of all rights, title, and interest in and to the '323 Patent and possesses all rights of recovery under the '323 Patent, including the right to recover damages for past infringement.

23. Each of the Patents-in-Suit is valid and enforceable.

24. Upon information and belief, Westell has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling wireless products compliant with the IEEE 802.11 standards and ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

25. Upon information and belief, NETGEAR has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling wireless products compliant with the IEEE 802.11 standards and ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

26. Upon information and belief, 2Wire has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling wireless products compliant with the IEEE 802.11 standards and ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

27. Upon information and belief, D-Link has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling wireless products compliant with the IEEE 802.11 standards and ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

28. Upon information and belief, Belkin has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the '222 Patent and '802 Patent in this District and elsewhere by making, using, offering for sale, importing, and/or selling wireless products compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the '222 Patent and '802 Patent.

29. Upon information and belief, Buffalo has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the '222 Patent and '802 Patent in this District and elsewhere by making, using, offering for sale, importing, and/or selling wireless

products compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the '222 Patent and '802 Patent.

30. Upon information and belief, Broadcom has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant Suppliers' ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

31. Upon information and belief, Atheros has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the '222 Patent and '802 Patent in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the '222 Patent and '802 Patent.

32. Upon information and belief, Marvell has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the '222 Patent and '802 Patent in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in one or more of the

Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the '222 Patent and '802 Patent.

33. Upon information and belief, Texas Instruments has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant Suppliers' ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

34. Upon information and belief, Infineon has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant Suppliers' ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

35. Upon information and belief, Intel has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the '222 Patent and '802 Patent in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in one or more of the Defendant

Suppliers' wireless products compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the '222 Patent and '802 Patent.

36. Upon information and belief, Best Buy has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards and the Defendant Suppliers' ADSL products compliant with the ITU G.992 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

37. Upon information and belief, Circuit City has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the '222 Patent and '802 Patent in this District and elsewhere by making, using, offering for sale, importing, and/or selling one or more of the Defendant Suppliers' wireless products compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the '222 Patent and '802 Patent.

38. Wi-LAN has no adequate remedy at law against Defendants' acts of infringement and, unless Defendants are enjoined from their infringement of the Patents-in-Suit, Wi-LAN will suffer irreparable harm.

39. Many of the Defendants have had knowledge of the Patents-in-Suit and have not ceased their infringing activities. These Defendants' infringement of the Patents-in-Suit has been and continues to be willful and deliberate. All the Defendants have knowledge of the Patents-in-Suit by way of this complaint and to the extent they do

not cease their infringing activities their infringement is and continues to be willful and deliberate.

40. Wi-LAN is in compliance with the requirements of 35 U.S.C. § 287.

41. Defendants, by way of their infringing activities, have caused and continue to cause Wi-LAN to suffer damages in an amount to be determined at trial.

PRAYER FOR RELIEF

WHEREFORE, Wi-LAN prays for the following relief:

A. A judgment in favor of Wi-LAN that Defendants have infringed, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit;

B. A permanent injunction, enjoining Defendants and their officers, directors, agents, servants, employees, affiliates, divisions, branches, subsidiaries, parents and all others acting in concert or privity with any of them from infringing, inducing the infringement of, or contributing to the infringement of the Patents-in-Suit;

C. Award to Wi-LAN the damages to which it is entitled under 35 U.S.C. § 284 for Defendants' past infringement and any continuing or future infringement up until the date Defendants are finally and permanently enjoined from further infringement, including both compensatory damages and treble damages for willful infringement;

E. A judgment and order requiring Defendants to pay the costs of this action (including all disbursements), as well as attorneys' fees as provided by 35 U.S.C. § 285;

F. Award to Wi-LAN pre-judgment and post-judgment interest on its damages; and

G. Such other and further relief in law or in equity to which Wi-LAN may be justly entitled.

DEMAND FOR JURY TRIAL

Wi-LAN demands a trial by jury of any and all issues triable of right before a jury.

DATED: October 31, 2007

Respectfully submitted,

MCKOOL SMITH, P.C.

Sam Baxter

Sam Baxter
Lead Attorney
Texas State Bar No. 01938000
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ATTORNEYS FOR WI-LAN INC.

Austin 40175v7

EXHIBIT A

US005282222A

United States Patent [19]

[11] Patent Number: 5,282,222

[45] Date of Patent: Jan. 25, 1994

Fattouche et al.

[54] METHOD AND APPARATUS FOR MULTIPLE ACCESS BETWEEN TRANSCEIVERS IN WIRELESS COMMUNICATIONS USING OFDM SPREAD SPECTRUM

[76] Inventors: Michel Fattouche, 156 Hawkwood Blvd. N.W., Calgary, Alberta, Canada, T3G 2T2; Hatim Zagloul, 402 - 1st Avenue, N.E., Calgary, Alberta, Canada, T2E 0B4

[21] Appl. No.: 861,725

[22] Filed: Mar. 31, 1992

[51] Int. Cl.[5] ... H04K 1/00

[52] U.S. Cl. ... 375/1; 380/34

[58] Field of Search ... 380/34; 375/1; 364/724.01, 827

[56] References Cited

U.S. PATENT DOCUMENTS

4,601,005	7/1986	Kilvington	
4,623,980	11/1986	Vary	364/724
4,893,266	1/1990	Deem	
4,914,699	4/1990	Dunn et al.	375/1 X
5,034,911	7/1991	Rachels	
5,063,560	11/1991	Yerbury et al.	375/1 X
5,089,982	2/1992	Gran et al	
5,151,919	9/1992	Dent	375/1

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OFDM for Data Communication over Mobile Radio FM Channels; Part II: Performance Improvement[1] by E. F. Casas and C. Leung, Department of Electrical Engineering University of British Columbia, Vancouver, B.C., Canada V6T 1W5.

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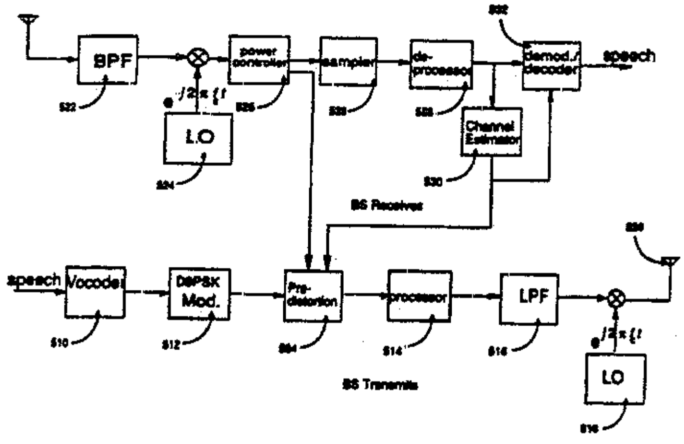
(List continued on next page.)

Primary Examiner—Tod R. Swann
Attorney, Agent, or Firm—Daniel L. Dawes

[57] ABSTRACT

A method for allowing a number of wireless transceivers to exchange information (data, voice or video) with each other. A first frame of information is multiplexed over a number of wideband frequency bands at a first transceiver, and the information transmitted to a second transceiver. The information is received and processed at the second transceiver. The information is differentially encoded using phase shift keying. In addition, after a pre-selected time interval, the first transceiver may transmit again. During the preselected time interval, the second transceiver may exchange information with another transceiver in a time duplex fashion. The processing of the signal at the second transceiver may include estimating the phase differential of the transmitted signal and pre-distorting the transmitted signal. A transceiver includes an encoder for encoding information, a wideband frequency division multiplexer for multiplexing the information onto wideband frequency voice channels, and a local oscillator for upconverting the multiplexed information. The apparatus may include a processor for applying a Fourier transform to the multiplexed information to bring the information into the time domain for transmission.

12 Claims, 23 Drawing Sheets



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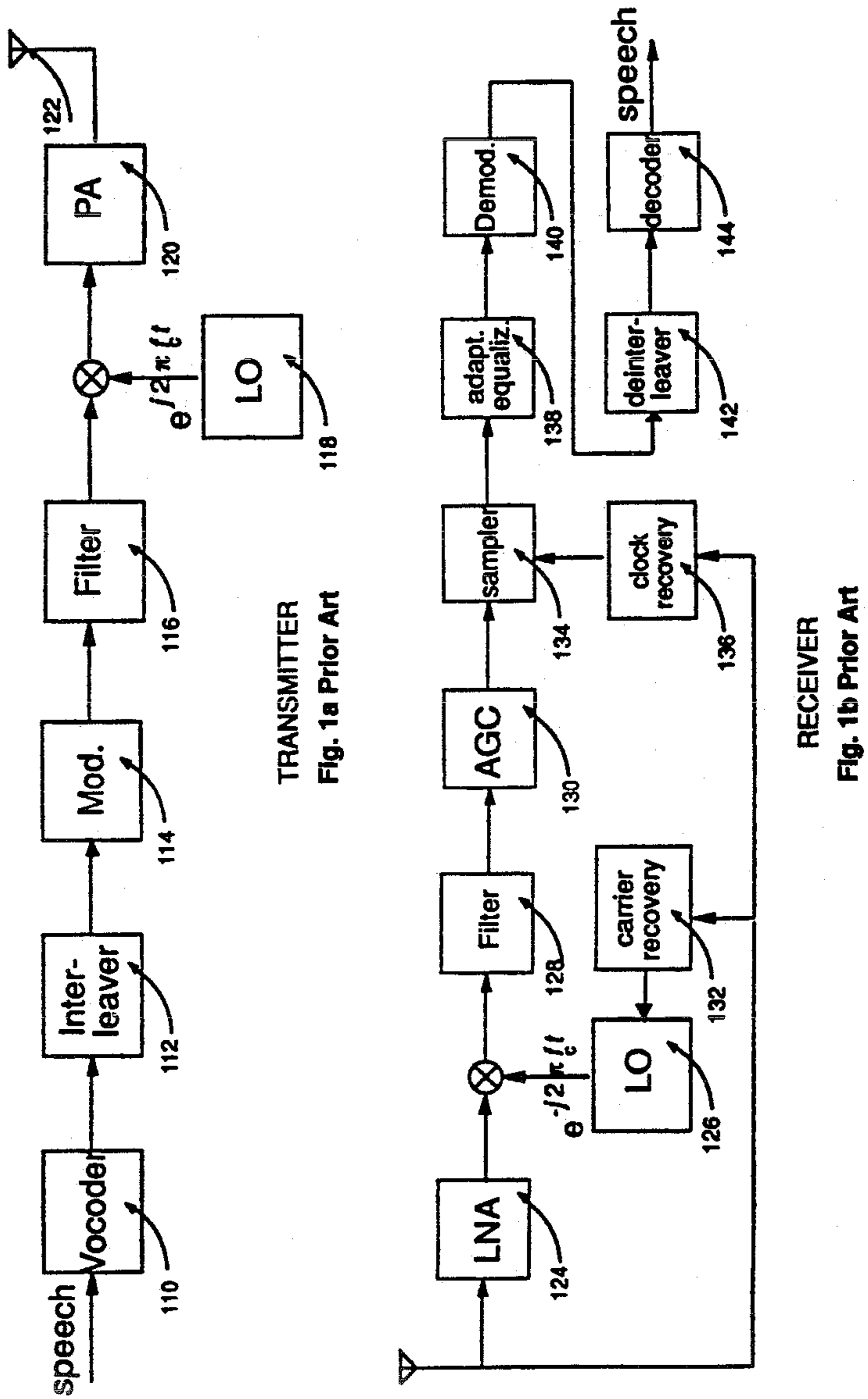


TRANSMITTER
Fig. 1a Prior Art

RECEIVER
Fig. 1b Prior Art

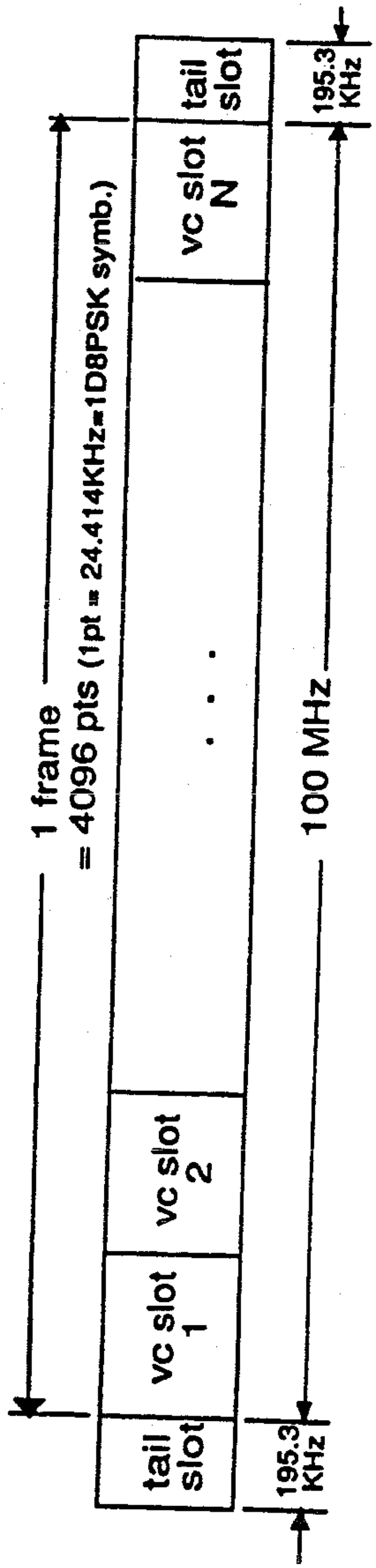
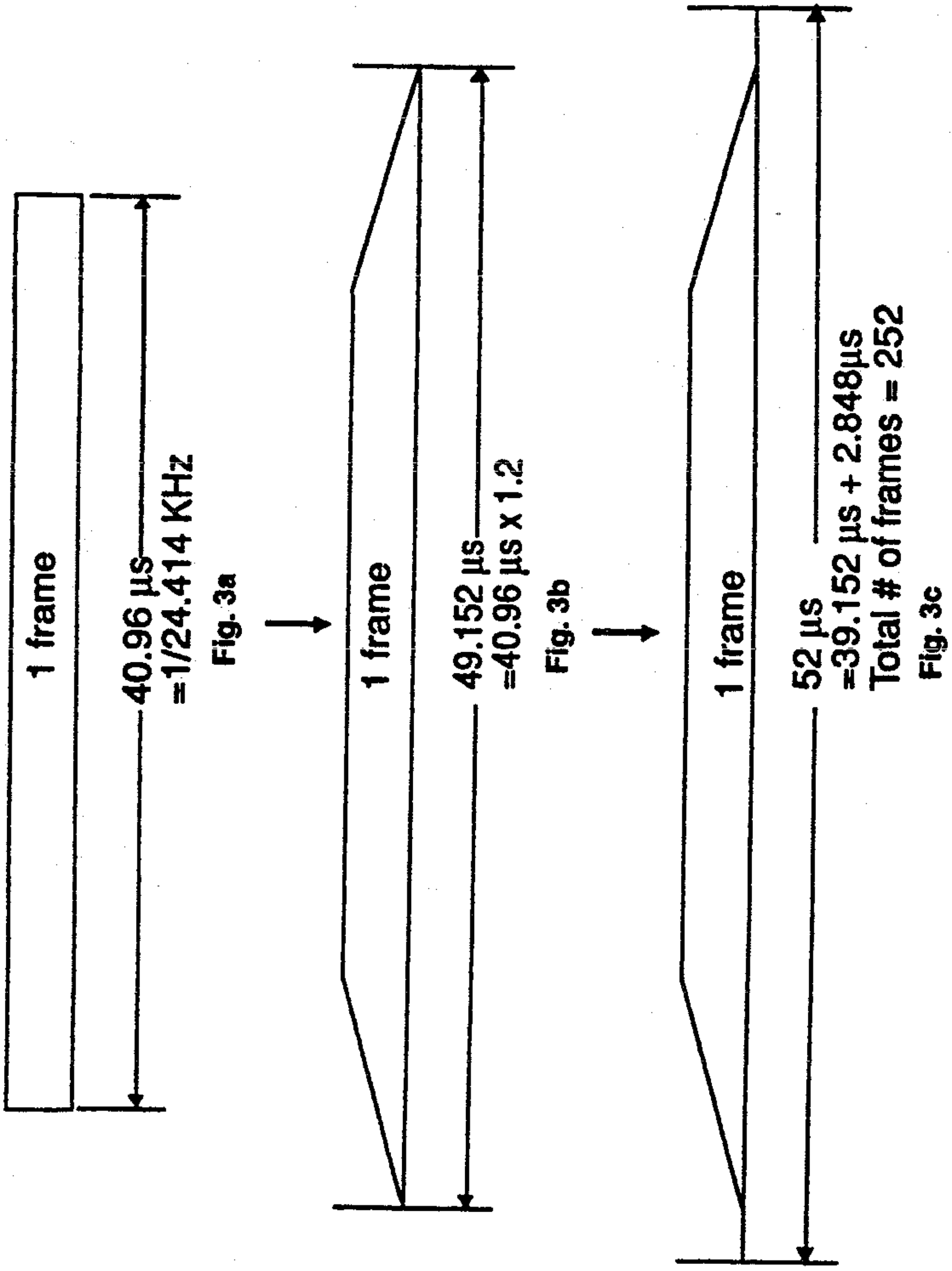

1 frame
= 4096 pts (1pt = 24.414KHz=1D8PSK symb.)
tail slot
vc slot 1
vc slot 2
. . .
vc slot N
tail slot
195.3 KHz
100 MHz
195.3 KHz

Fig. 2


1 frame
40.96 µs
=1/24.414 KHz
Fig. 3a
1 frame
49.152 µs
=40.96 µs x 1.2
Fig. 3b
1 frame
52 µs
=39.152 µs + 2.848µs
Total # of frames = 252
Fig. 3c

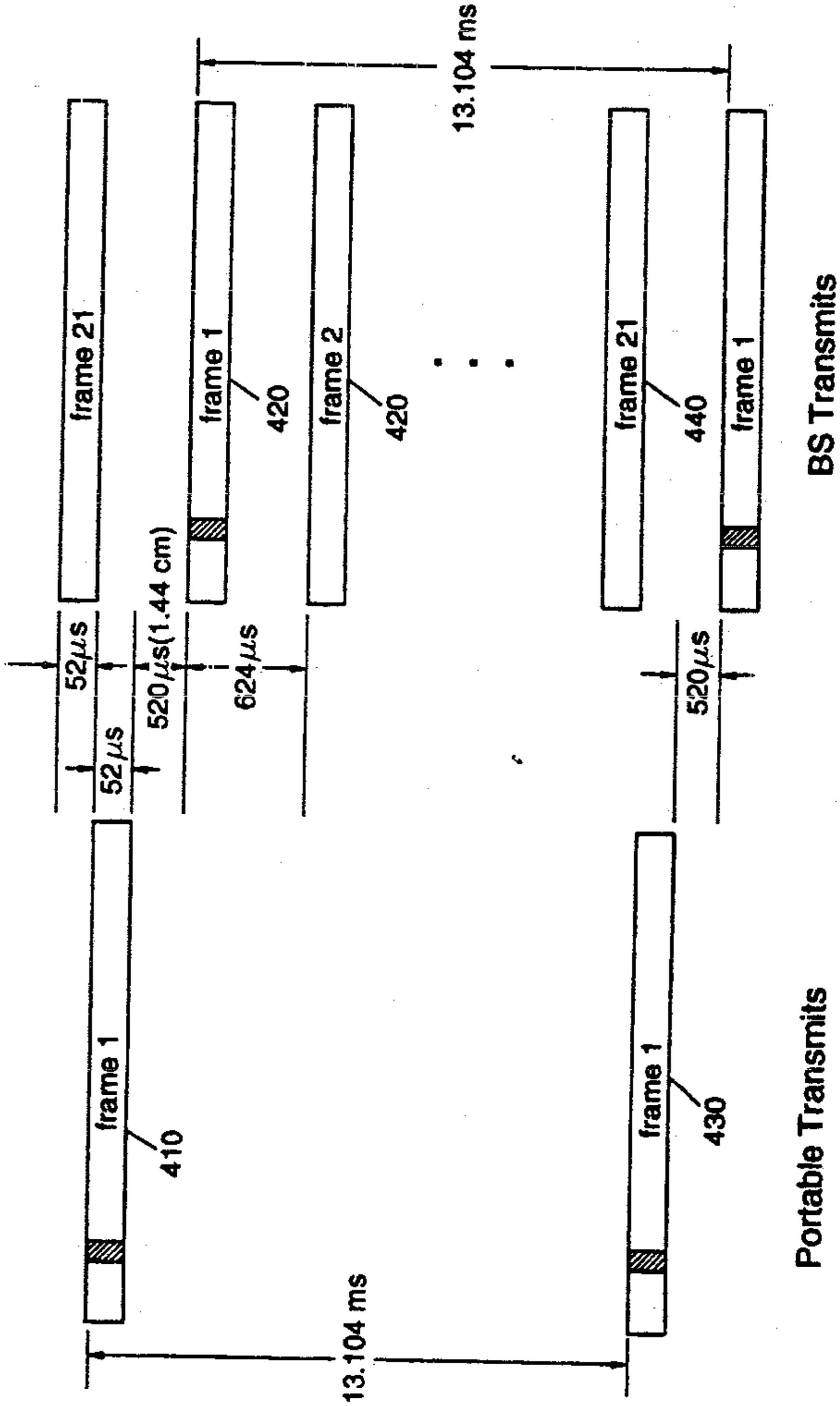
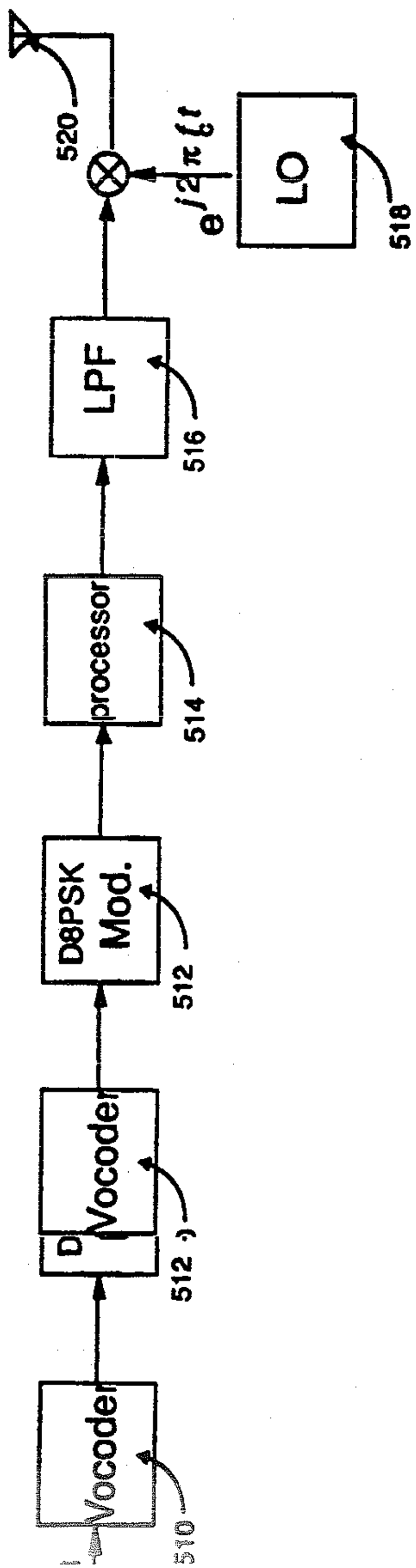

13.104 ms
frame 21
frame 1
420
frame 2
420
frame 21
440
frame 1
BS Transmits
52μs
52μs
520μs(1.44 cm)
624μs
520μs
frame 1
410
frame 1
430
Portable Transmits
13.104 ms

Fig. 4



Portable Transmits

Fig. 5a

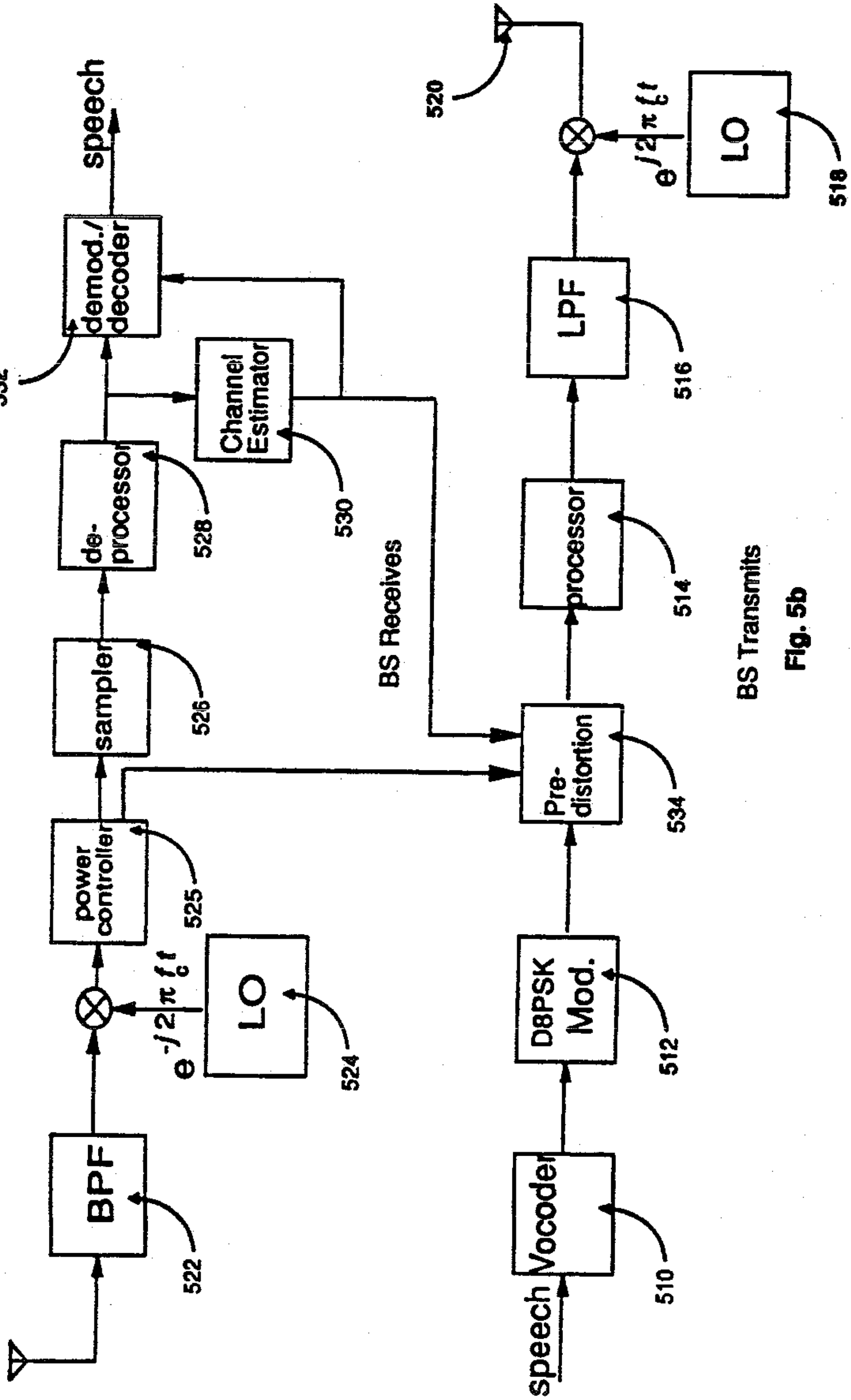
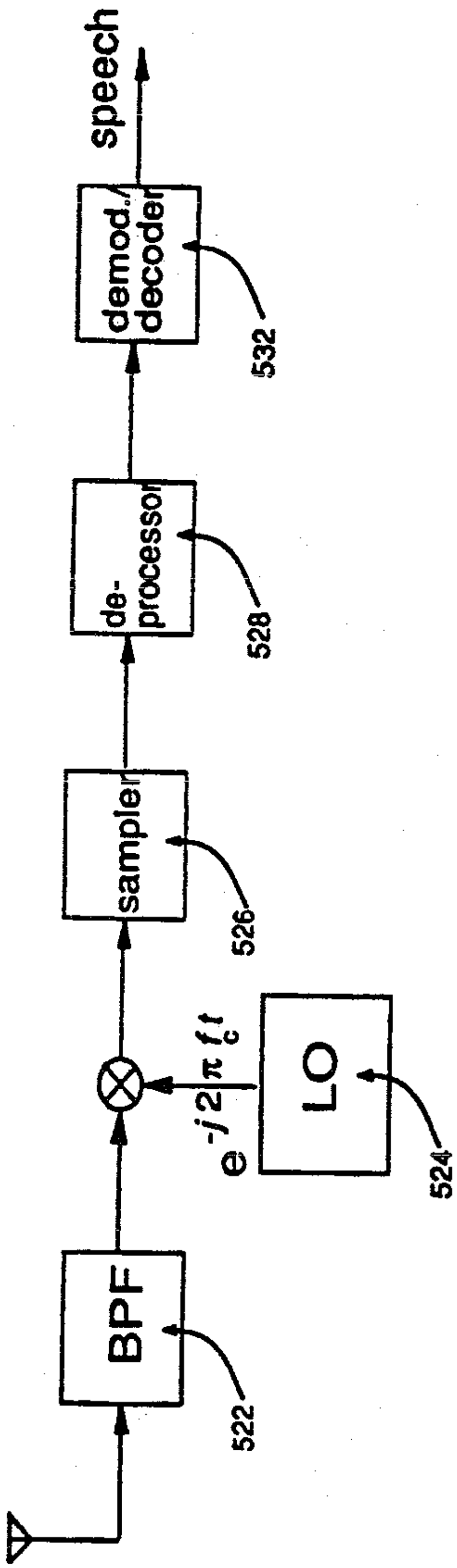
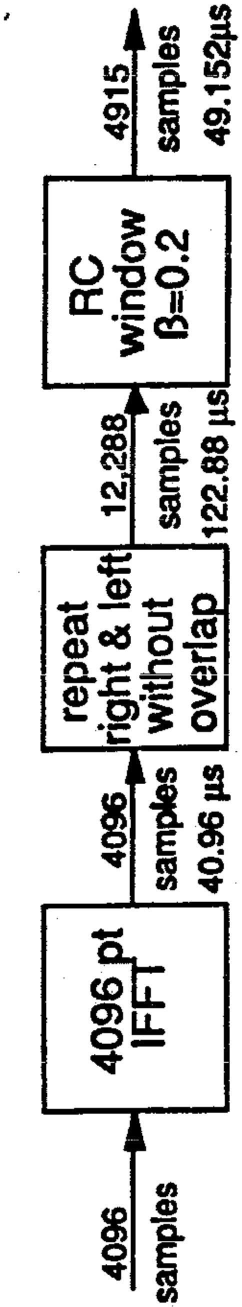

BPF
522
LO
524
$e^{-j2\pi f_c t}$
power controller
525
sampler
526
de-processor
528
Channel Estimator
530
demod./decoder
532
speech
BS Receives
speech
Vocoder
510
D8PSK Mod.
512
Pre-distortion
534
processor
514
LPF
516
LO
518
$e^{j2\pi f_c t}$
520
BS Transmits

Fig. 5b



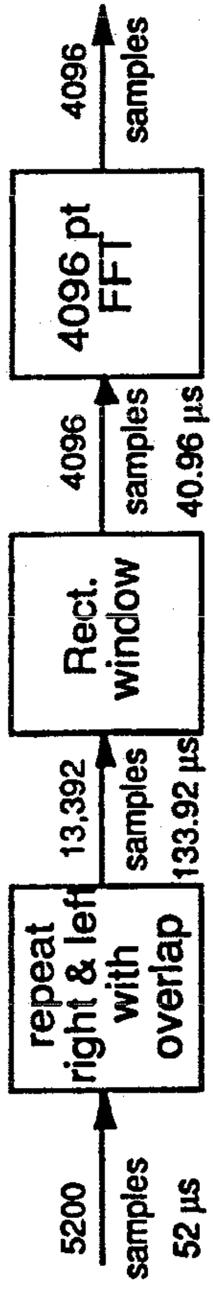
Portable Receives

Fig. 5c



Processor

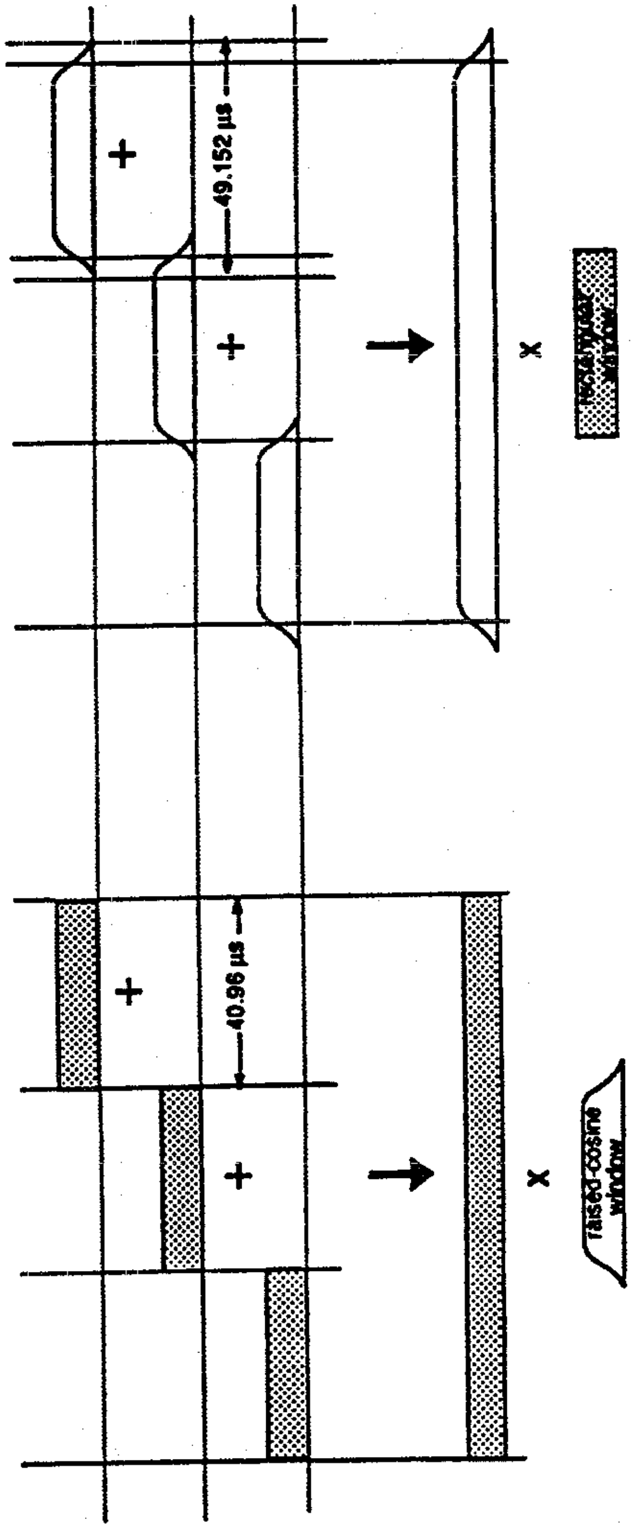
Fig. 6a



De-processor

Fig. 6b

† a sample above is a complex sample.



Repeat right & left with overlap followed by a rectangular window

(last 2 blocks in de-processor)

Repeat right & Left without overlap followed by a raised cosine window

(last 2 blocks in processor)

Fig. 6c

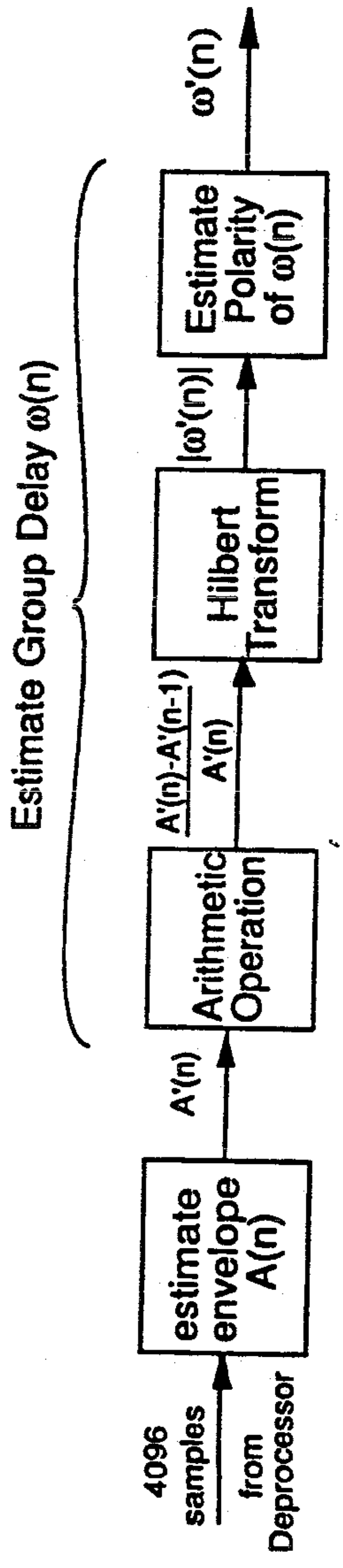

4096 samples from Deprocessor
estimate envelope A(n)
A'(n)
Arithmetic Operation
A'(n)-A'(n-1) / A'(n)
Hilbert Transform
|ω'(n)|
Estimate Polarity of ω(n)
ω'(n)
Estimate Group Delay ω(n)

Fig. 7a

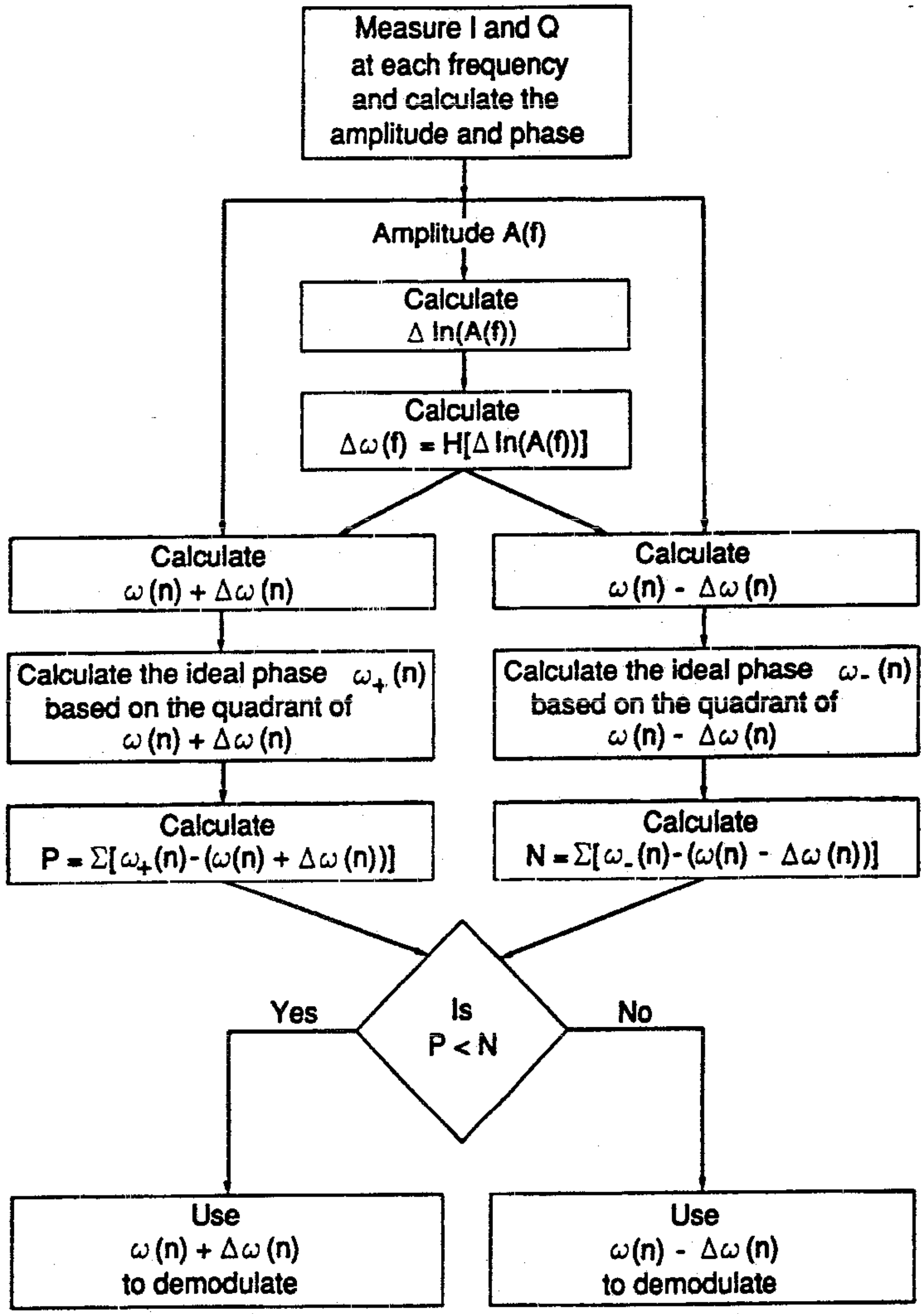

Measure I and Q at each frequency and calculate the amplitude and phase
Amplitude A(f)
Calculate Δ ln(A(f))
Calculate Δω(f) = H[Δ ln(A(f))]
Calculate ω(n) + Δω(n)
Calculate ω(n) - Δω(n)
Calculate the ideal phase ω+(n) based on the quadrant of ω(n) + Δω(n)
Calculate the ideal phase ω-(n) based on the quadrant of ω(n) - Δω(n)
Calculate P = Σ[ω+(n)-(ω(n) + Δω(n))]
Calculate N = Σ[ω-(n)-(ω(n) - Δω(n))]
Is P < N
Yes
No
Use ω(n) + Δω(n) to demodulate
Use ω(n) - Δω(n) to demodulate

Fig. 7b

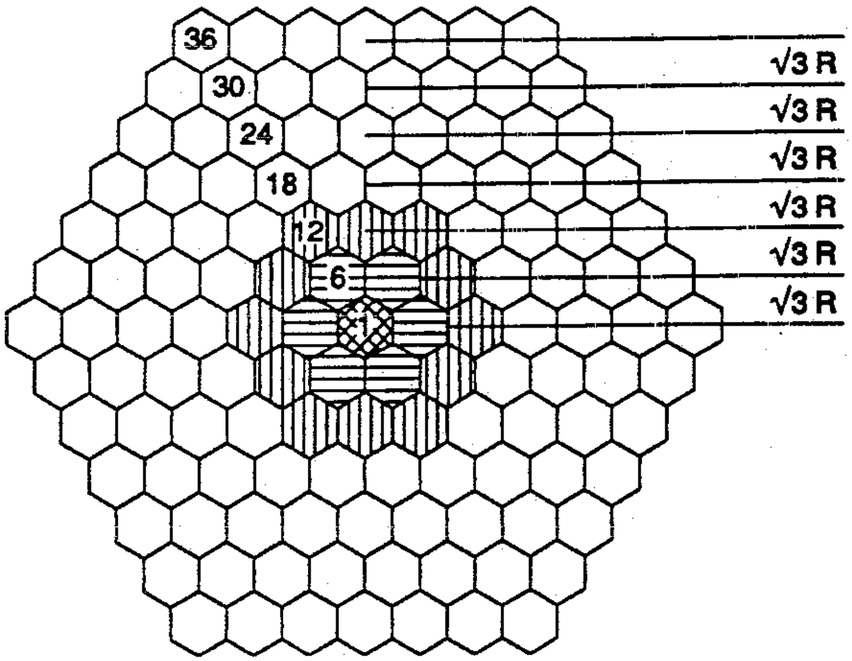


Fig. 8a

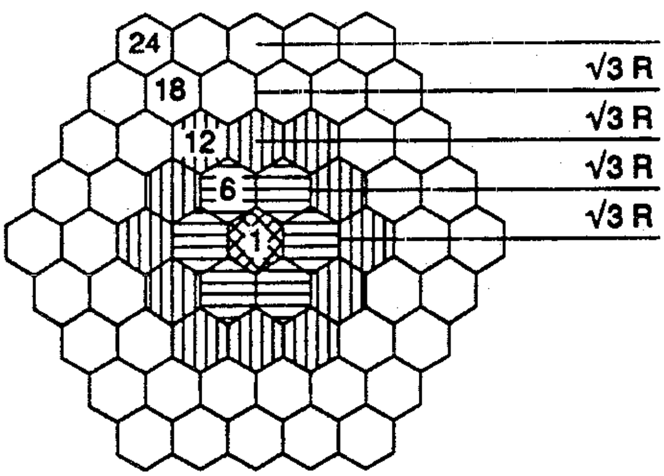


Fig. 8b

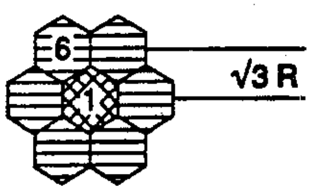


Fig. 8c

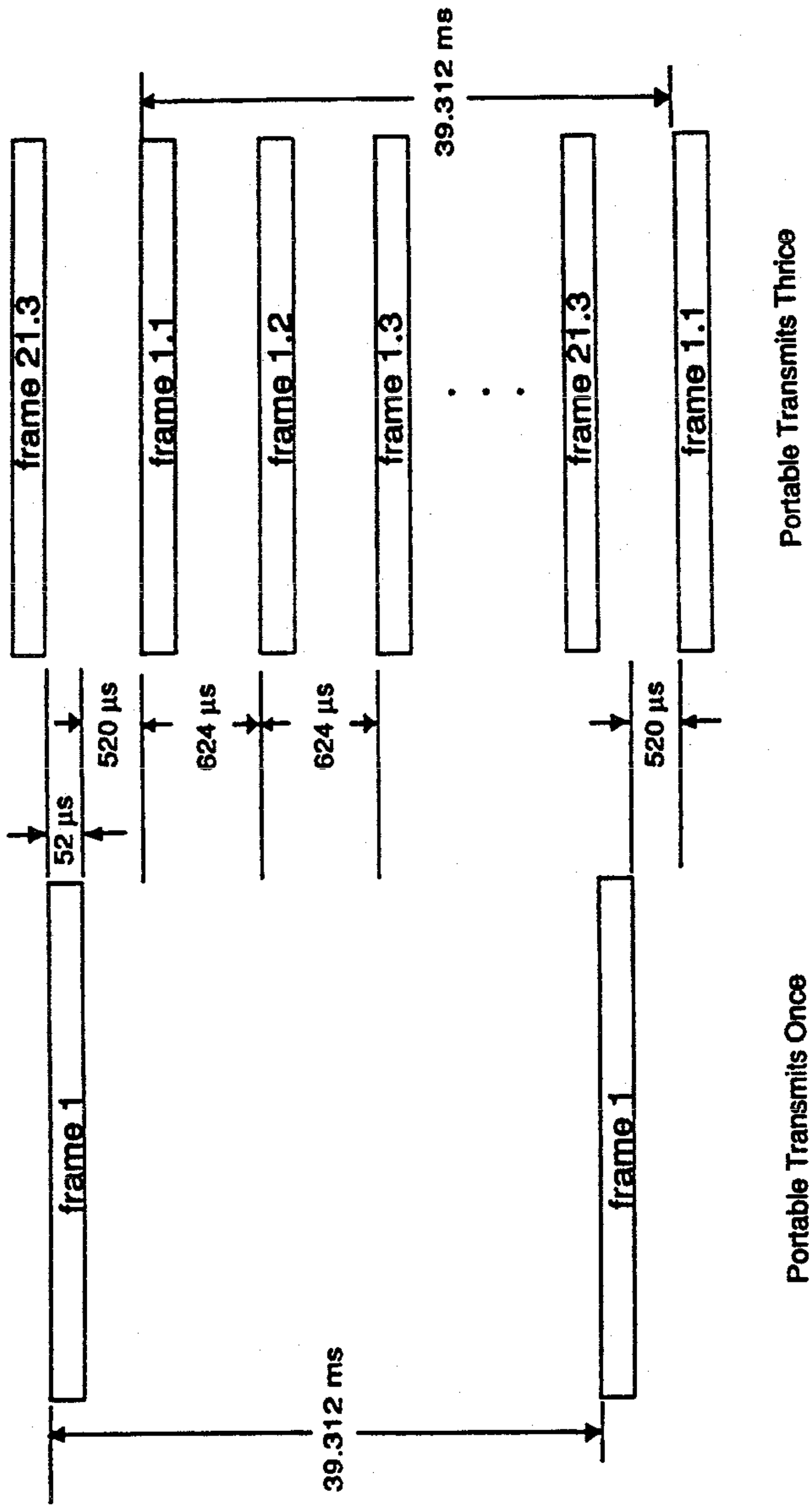

39.312 ms
frame 21.3
frame 1.1
frame 1.2
frame 1.3
frame 21.3
frame 1.1
52 µs
520 µs
624 µs
624 µs
520 µs
frame 1
frame 1
39.312 ms
Portable Transmits Thrice
Portable Transmits Once

Fig. 9a

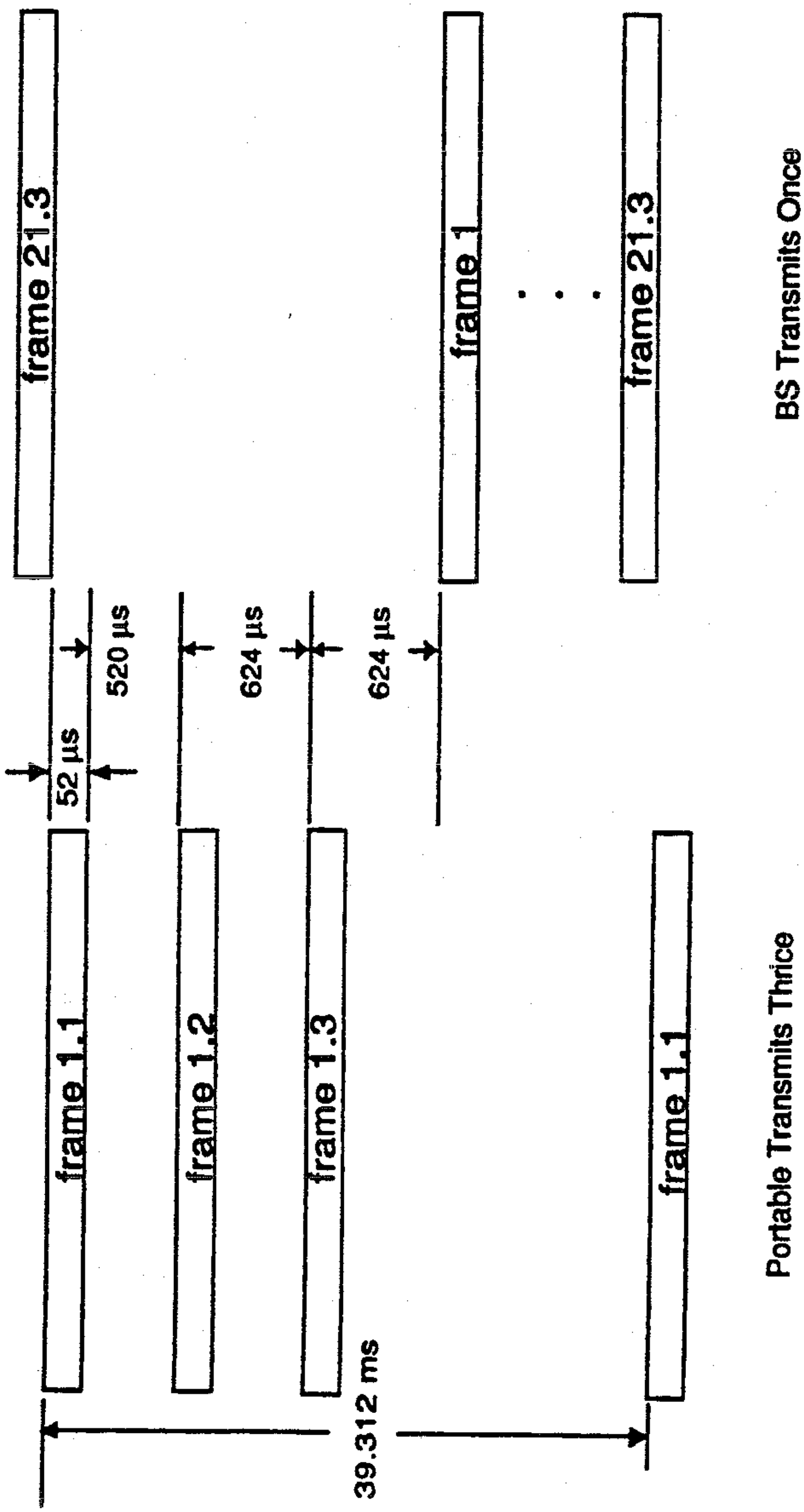
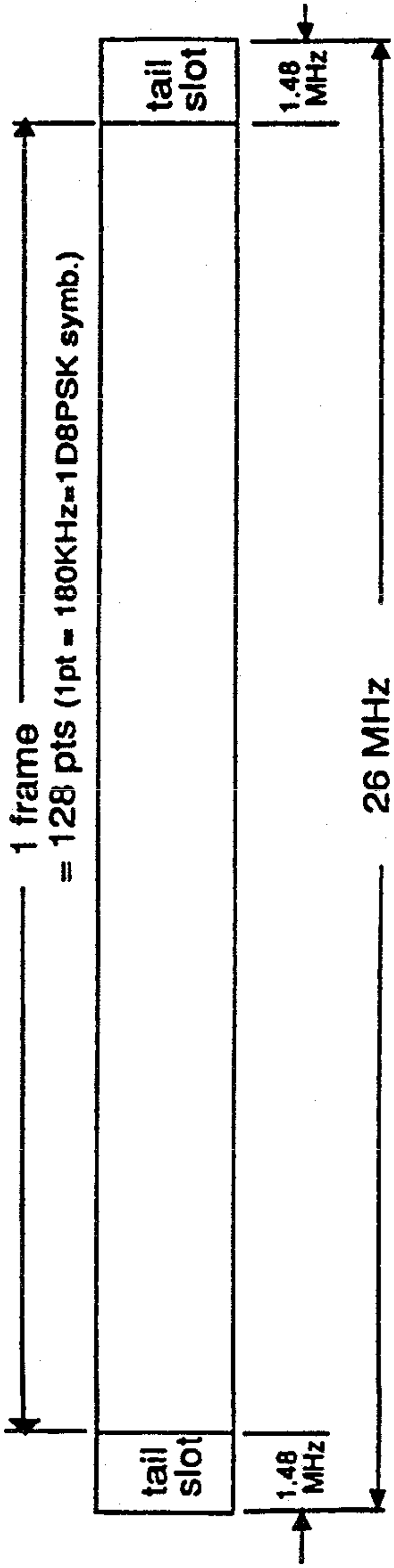

frame 21.3
frame 1
frame 21.3
BS Transmits Once
52 µs
520 µs
624 µs
624 µs
frame 1.1
frame 1.2
frame 1.3
frame 1.1
Portable Transmits Thrice
39.312 ms

Fig. 9b



Wideband OFDM

Fig. 10

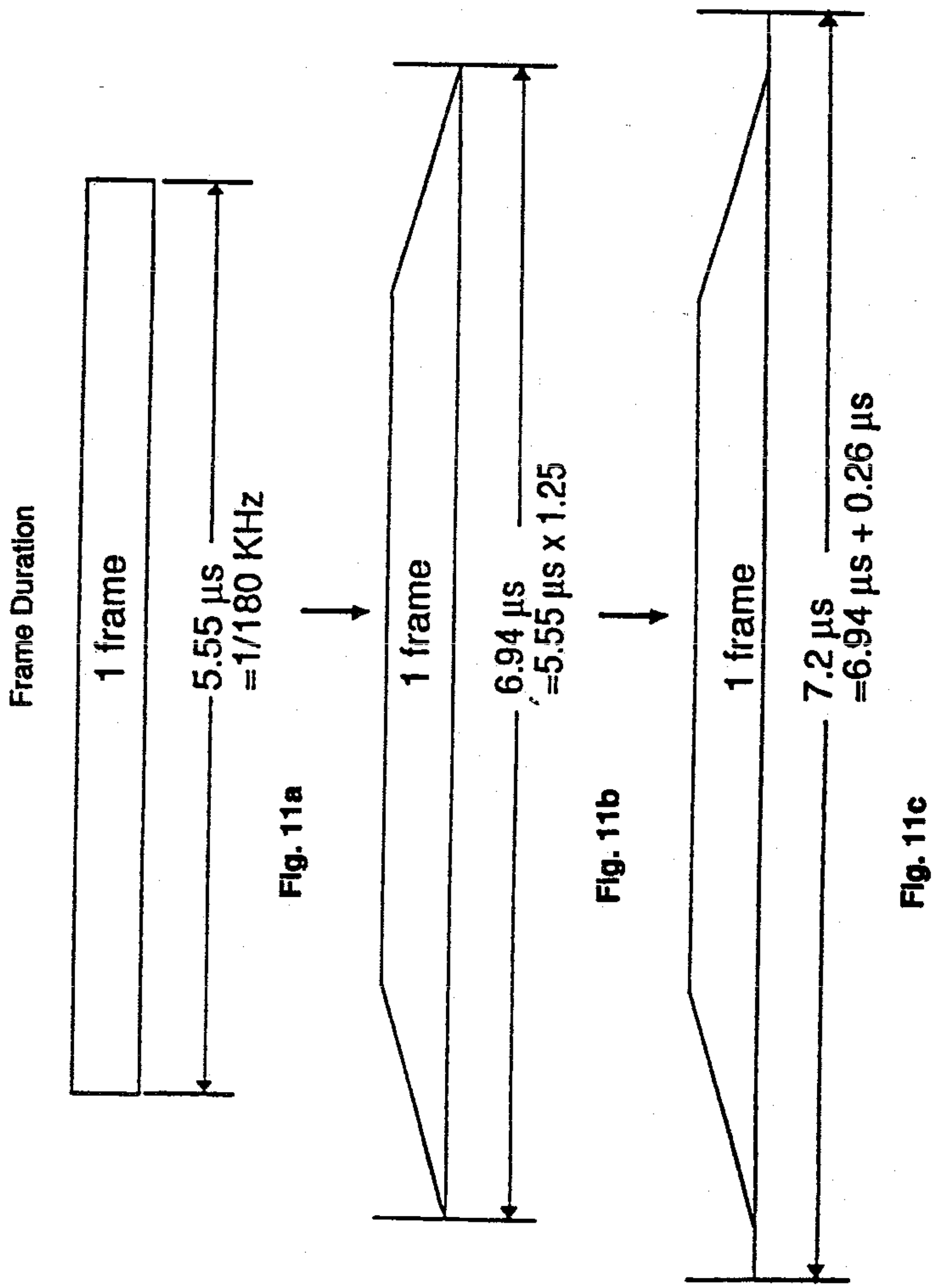


Fig. 11a

Fig. 11b

Fig. 11c

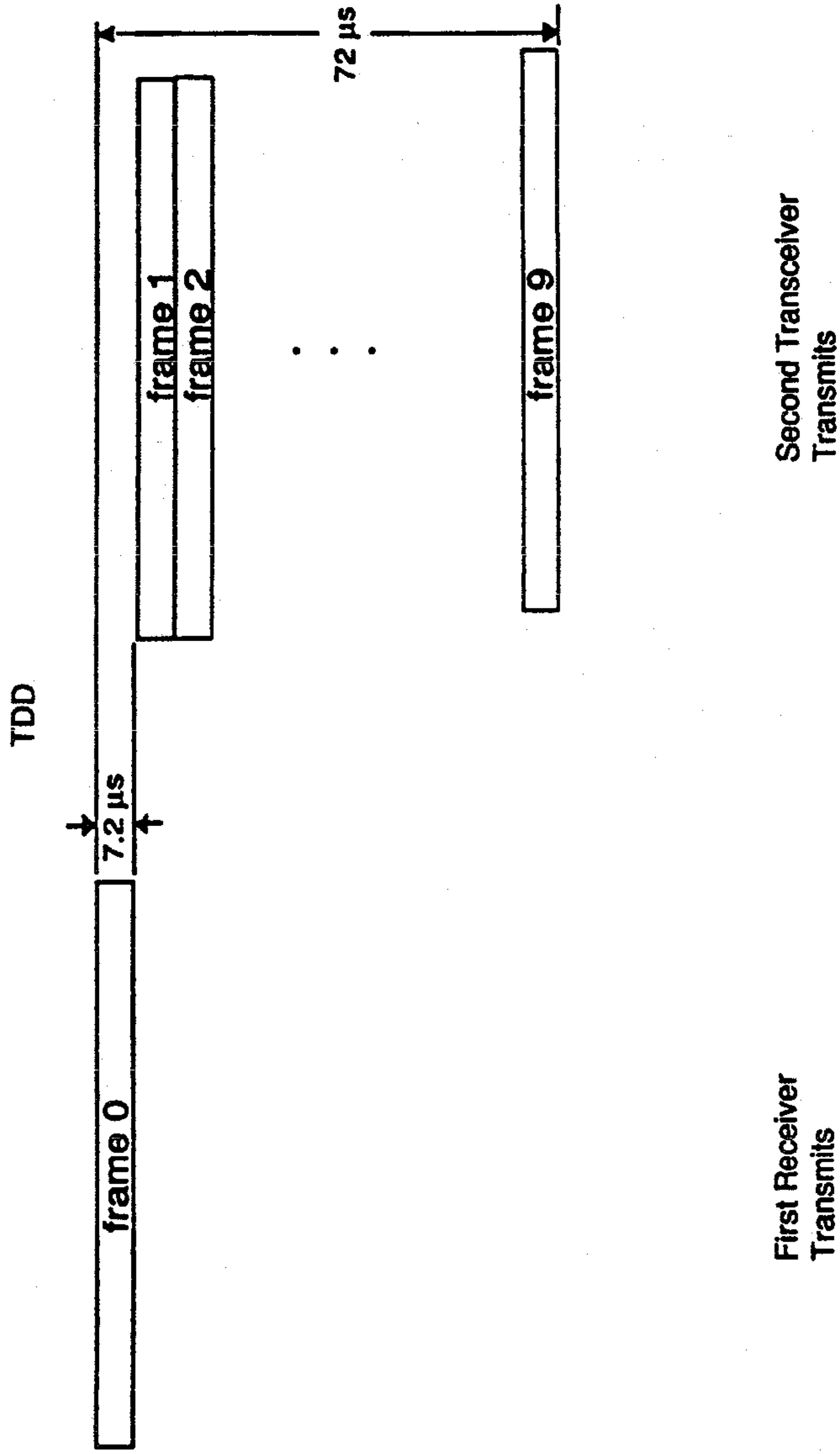
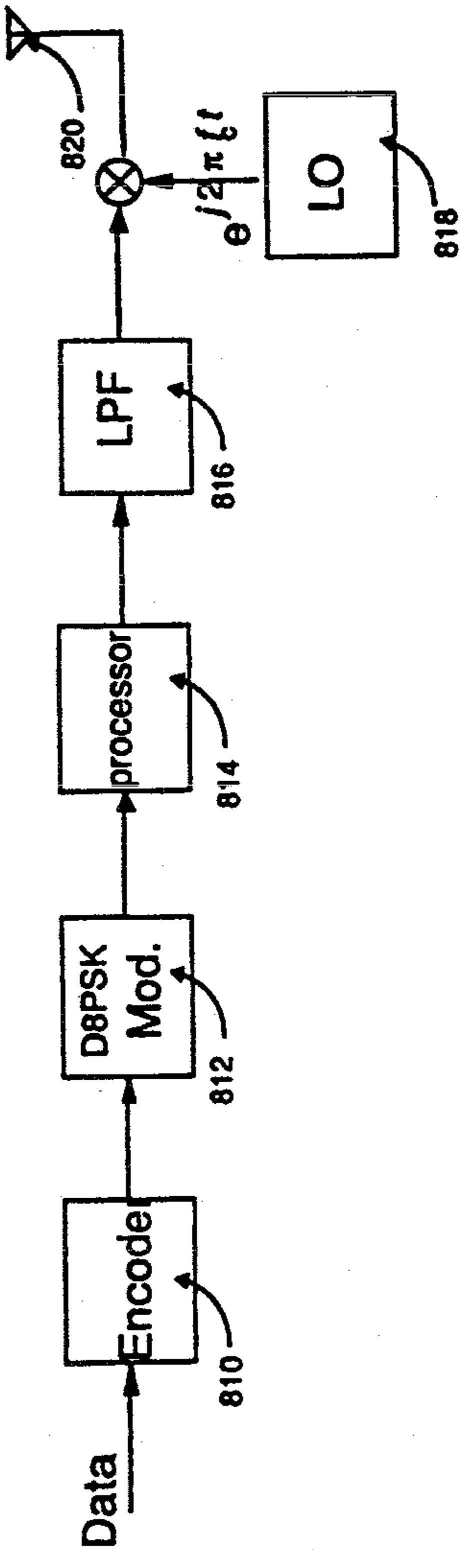
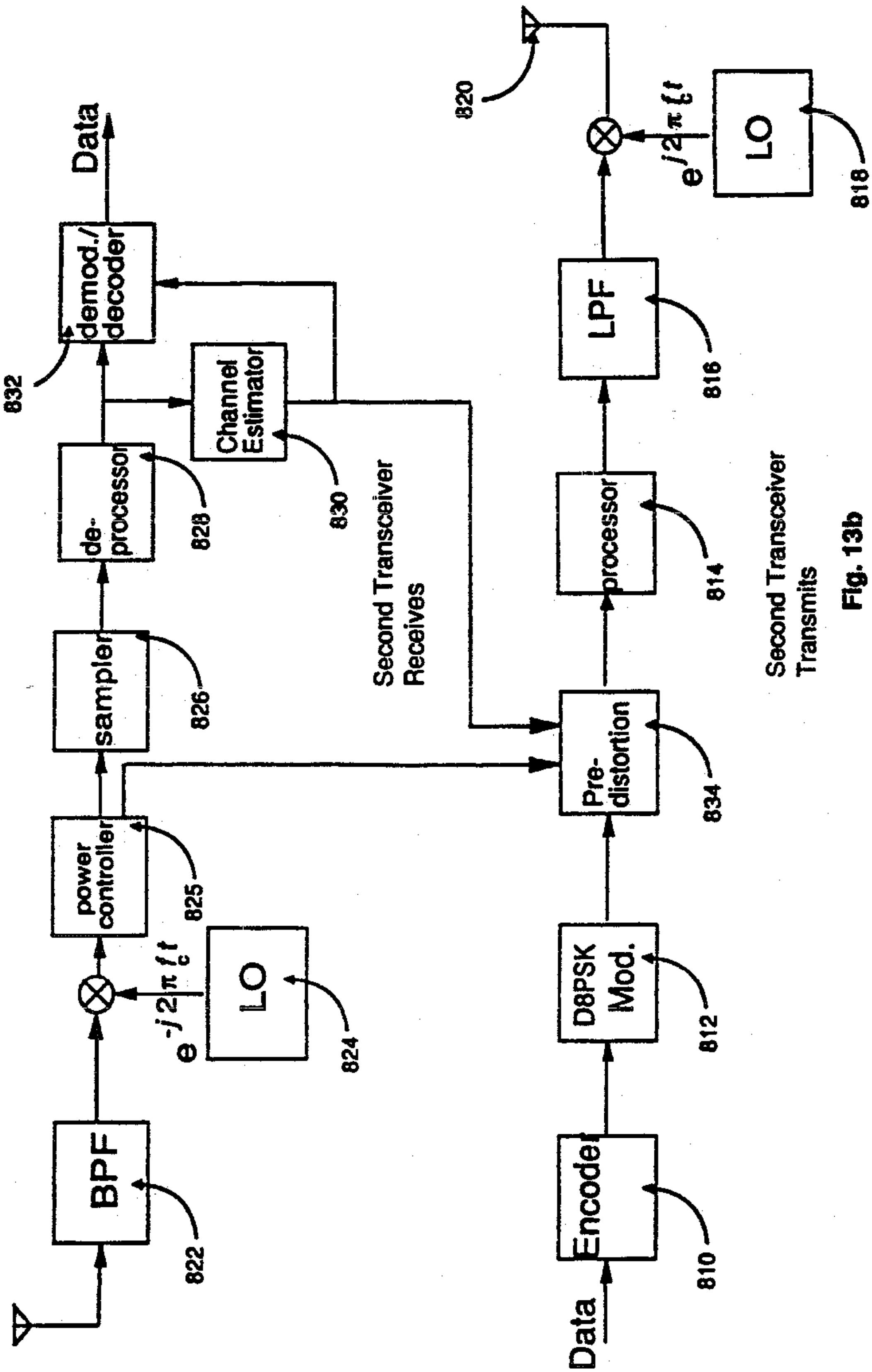

TDD
72 µs
7.2 µs
frame 0
frame 1
frame 2
frame 9
First Receiver Transmits
Second Transceiver Transmits

Fig. 12



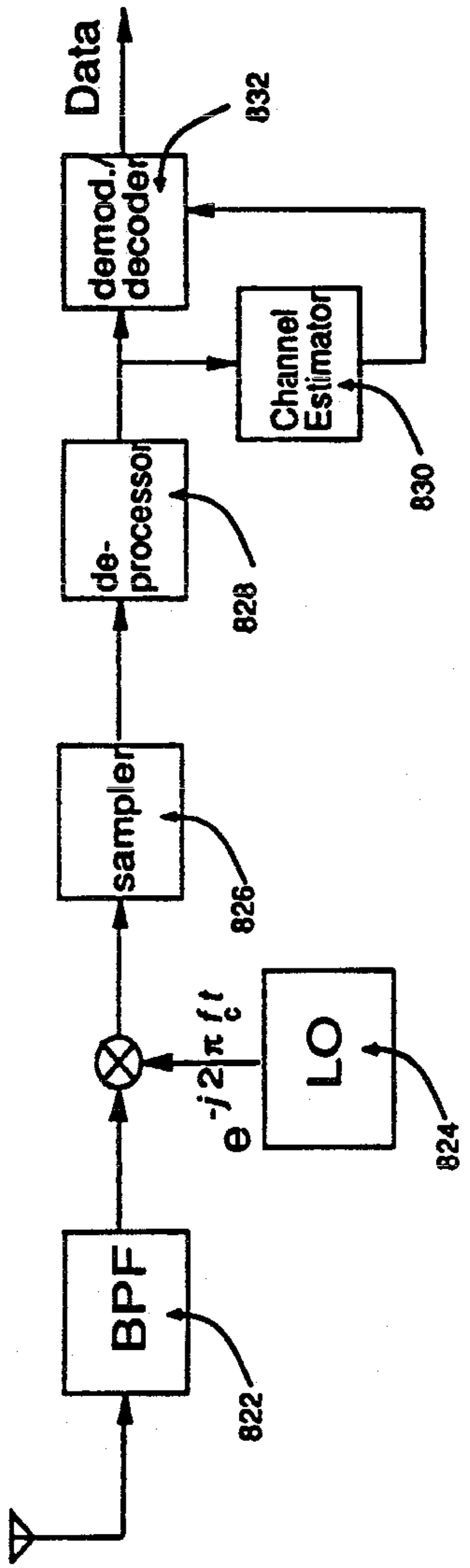
First Transceiver Transmits

Fig. 13a



Data
demod./decoder
832
Channel Estimator
830
de-processor
828
sampler
826
power controller
825
$e^{-j2\pi f_c t}$
LO
824
BPF
822
Second Transceiver Receives
820
$e^{j2\pi f_c t}$
LO
818
LPF
816
processor
814
Pre-distortion
834
D8PSK Mod.
812
Encoder
810
Data
Second Transceiver Transmits

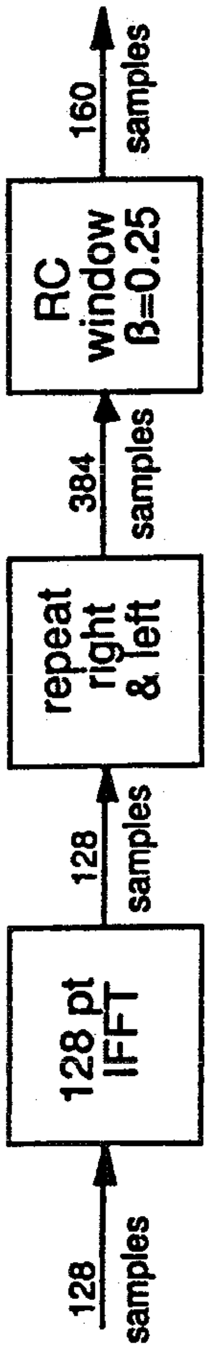
Fig. 13b



First Transceiver Receives

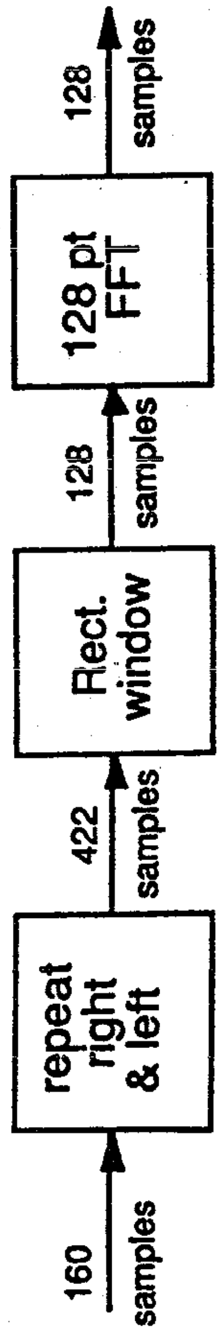
Fig. 13c

Digital Signal Processors



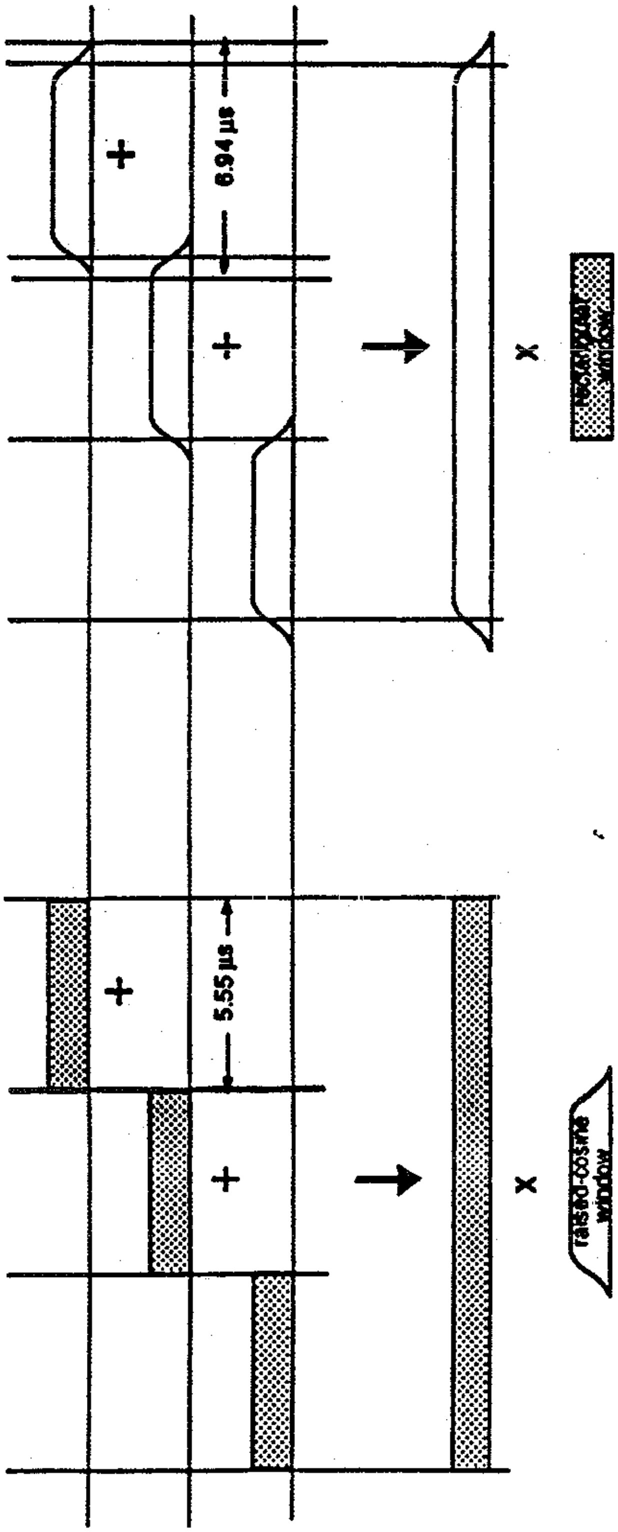
Processor

Fig. 14a



De-Processor

Fig. 14b



Repeat right & Left without overlap followed by a raised cosine window

(last 2 blocks in processor)

Repeat right & left with overlap followed by a rectangular window

(last 2 blocks in de-processor)

Fig. 14c

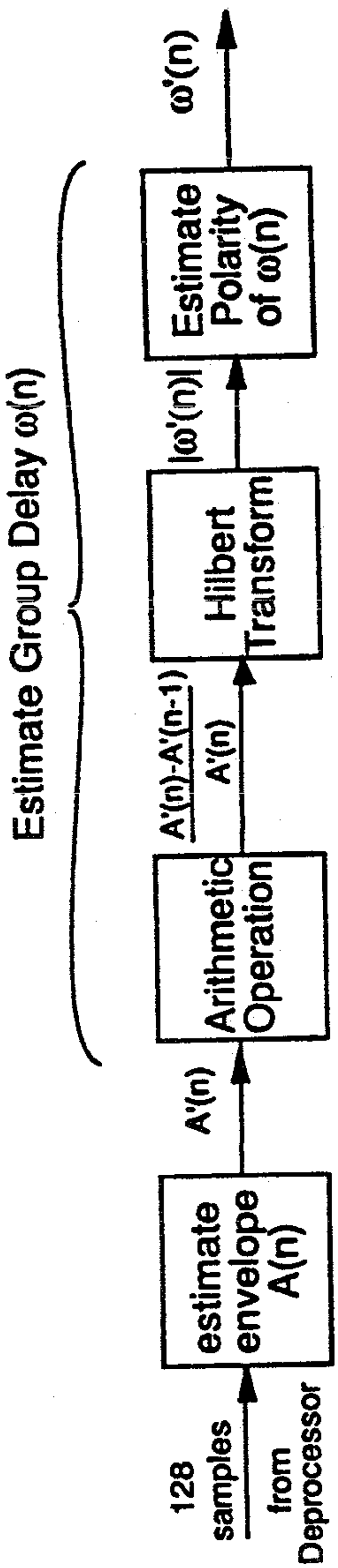

Estimate Group Delay ω(n)
128 samples from Deprocessor
estimate envelope A(n)
A'(n)
Arithmetic Operation
A'(n)-A'(n-1) / A'(n)
Hilbert Transform
|ω'(n)|
Estimate Polarity of ω(n)
ω'(n)

Fig. 15

METHOD AND APPARATUS FOR MULIPLE ACCESS BETWEEN TRANSCEIVERS IN WIRELESS COMMUNICATIONS USING OFDM SPREAD SPECTRUM

FIELD OF THE INVENTION

This invention relates to voice and data transmission in wireless communications, and particularly between fixed and portable transmitters and receivers.

CLAIM TO COPYRIGHT

BACKGROUND AND SUMMARY OF THE INVENTION

This patent document presents a new multiple access technique for Personal Communication Networks (PCN). Personal communication networks are networks that allow individuals and equipment to exchange information with each other anywhere at anytime through voice, data or video. PCN typically include a number of transceivers, each capable of transmitting and receiving information (voice, data or video) in the form of electromagnetic signals. The transceivers may be fixed or portable, and may be identical or one or more of them may be more complex

The system must allow the transceivers to access each other to enable the exchange of information. When there are a number of transceivers, multiple access, that is, access by more than one transceiver to another transceiver, must be allowed.

One of the constraints of designing a PCN is that a transceiver, or portable radio unit, must be small in size. The smaller the unit, the better for portability. The small size of the units means only small and light-weight power sources can be used. If the portable is to be used for any length of time, it must therefore consume minimal power.

Also, to allow use of the radio frequency spectrum without obtaining a license in North America, the system must use a spread spectrum and satisfy federal regulations. In part, these regulations impose limits on the power and the frequency spread of the signals exchanged between the transceivers. An object of an aspect of this invention is to satisfy those requirements.

Also, transceivers talk to each other over a fixed bandwidth. Because of the limited availability of the RF spectrum, the system must be bandwidth efficient yet at the same time maintain high quality exchange of information at all times in one of the most hostile channels known in communication. The new multiple access technique proposed here addresses all these issues.

The new access technique has a low Bit Error Probability (BER) as well as a low probability of dropped and blocked calls. This is due to the fact that the access technique is robust against multipath, Doppler shifts, impulse noise and narrowband interference. It has a low cochannel interference and little or no intersymbol interference.

The new access technique can offer up to 38 times the capacity of analog FM. It includes in one aspect wideband orthogonal frequency division multiplexing of the information to be exchanged, and may include slow Frequency Hopping (FH). The technique is implemented using Digital Signal Processors (DSP) replacing conventional analog devices. The system operates with relatively small cells. In other aspects, dynamic channel allocation and voice activation may be used to improve the capacity of the system.

Advantages of the present invention include:

1. It can be used indoors as well as outdoors using the same transceivers. If data is to be exchanged, as opposed to voice, the transceiver preferably contains an estimator to allow pre-distortion and post-distortion of the transmitted signal.
2. The system, as compared with prior art systems omits the clock or carrier recovery, automatic gain control or passband limiter, power amplifier, an equalizer or an interleaver-deinterleaver, and therefore has low complexity.
3. The system offers good speech quality, as well as low probabilities of dropped and blocked calls. It is robust against Doppler and multipath shifts. It is also robust against both impulse noise and narrowband interference.
4. The system is flexible, such that at the expense of increased complexity of the DSP receiver it can be applied over noncontiguous bands. This is accomplished by dividing a 100 MHz (in one of the exemplary embodiments described here) band into several subbands each accommodating an integer number of voice channels.
5. The system offers low frame delay (less than 26.2 ms in the exemplary cellular embodiment described here). The transceiver requires low average transmitted power (of the order of 20 μW in the exemplary cellular embodiment described here) which means power saving as well as enhanced biological safety.
6. The system offers up to a 38 fold increase in capacity over the North American Advanced Mobile Phone System (AMPS) which uses analog frequency modulation.

Operation of the system in accordance with the techniques described in this disclosure may permit compliance with technical requirements for spread spectrum systems.

There is therefore disclosed in one aspect of the invention a method for allowing a number of wireless transceivers to exchange information (data, voice or video) with each other. In the method, a first frame of information is multiplexed over a number of frequency bands at a first transceiver, and the information transmitted to a second transceiver. In a cellular implementation, the second transceiver may be a base station with capacity to exchange information with several other transceivers. The information is received and processed at the second transceiver. The frequency bands are selected to occupy a wideband and are preferably contiguous, with the information being differentially encoded using phase shift keying

A signal may then be sent from the second transceiver to the first transceiver and de-processed at the first transceiver. In addition, after a preselected time interval, the first transceiver transmits again. During

the preselected time interval, the second transceiver may exchange information with another transceiver in a time duplex fashion.

The processing of the signal at the second transceiver ma include estimating the phase differential of the transmitted signal and predistorting the transmitted signal.

The time intervals used by the transceivers may be assigned so that a plurality of time intervals are made available to the first transceiver for each time interval made available to the second transceiver while the first transceiver is transmitting, and for a plurality of time intervals to be made available to the second transceiver for each time interval made available to the first transceiver otherwise. Frequencies may also be borrowed by one base station from an adjacent base station. Thus if one base station has available a first set of frequencies, and another a second set of distinct frequencies, then a portion of the frequencies in the first set may be temporarily re-assigned to the second base station.

In an implementation of the invention for a local area network, each transceiver may be made identical except for its address.

Apparatus for carrying-out the method of the invention is also described here. The basic apparatus is a transceiver which will include an encoder for encoding information, a wideband frequency division multiplexer for multiplexing the information onto wideband frequency voice channels, and a local oscillator for upconverting the multiplexed information. The apparatus may include a processor for applying a Fourier transform to the multiplexed information to bring the information into the time domain for transmission.

BRIEF DESCRIPTION OF THE DRAWINGS

There will now be described a preferred embodiment of the invention, with reference to the drawings, by way of illustration, in which like numerals denote like elements and in which:

FIGS. **1***a* and **1***b* are schematics of a prior art receiver and transmitter respectively;

FIG. **2** is a schematic showing the use of the available frequencies according to one aspect of the invention for use with cellular applications;

FIG. **3***a* is a schematic showing an idealized pulse for transmission over a cellular system;

FIG. **3***b* is a schematic showing a modified version of the pulse shown in FIG. **3***a*;

FIG. **3***c* is a schematic showing a further modified version of the pulse shown in FIG. **3***a*;

FIG. **4** is a schematic showing an exemplary protocol for cellular communication;

FIG. **5***a* is a block diagram showing the structure and function of an embodiment of the transmitter of a cellular portable in accordance with the invention;

FIG. **5***b* is a block diagram showing the structure and function of an embodiment of the transmitter and receiver of a cellular base station in accordance with the invention;

FIG. **5***c* is a block diagram showing the structure and function of an embodiment of the receiver of a cellular portable in accordance with the invention;

FIG. **6***a* is a flow diagram showing the function of the processor in either of FIGS. **5***a* or **5***b*;

FIG. **6***b* is a schematic showing the function of the deprocessor in either of FIGS. **5***b* or **5***c*;

FIG. **6***c* is a schematic further illustrating the operation of the processor and deprocessor shown in FIGS. **6***a* and **6***b*;

FIG. **7***a* is a schematic showing the structure and function of the channel estimator in FIG. **5***b*;

FIG. **7***b* is a flow chart showing the operation of the channel estimator of FIGS. **5***b* and **7***a*;

FIGS. **8***a*, **8***b* and **8***c* are respectively schematics of **126**, **63** and **7** cell reuse patterns;

FIGS. **9***a* and **9***b* are schematics showing transmit protocols according to one aspect of the invention;

FIG. **10** is a schematic showing the use of the available frequencies according to another aspect of the invention for use with local area network applications;

FIG. **11***a* is a schematic showing an idealized pulse for transmission over a local network system;

FIG. **11***b* is a schematic showing a modified version of the pulse shown in FIG. **11***a*;

FIG. **11***c* is a schematic showing a further modified version of the pulse shown in FIG. **11***a*;

FIG. **12** is a schematic showing a preferred protocol for local area network communication;

FIG. **13***a* is a block diagram showing the structure and function of an embodiment of the transmitter of a local area network transceiver according to the invention;

FIG. **13***b* is a block diagram showing the structure and function of an embodiment of a further local area network transceiver according to the invention;

FIG. **13***c* is a block diagram showing the structure and function of an embodiment of the receiver of a local area network transceiver according to the invention;

FIG. **14***a* is a flow diagram showing the function of the processor in either of FIGS. **13***a* or **13***b*;

FIG. **14***b* is a schematic showing the function of the deprocessor in either of FIGS. **13***b* or **13***c*;

FIG. **14***c* is a schematic further illustrating the operation of the processor and deprocessor shown in FIGS. **14***a* and **14***b*; and

FIG. **15** is a schematic showing the structure and function of the channel estimator in FIG. **13***b*.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Introduction

The benefits of the invention can be readily appreciated with reference to FIG. **1**, which shows a prior art transmitter/receiver configuration for a portable unit. The transmitter includes a vocoder **110**, an interleaver **112**, a modulator **114**, a filter **116**, local oscillator **118**, power amplifier (PA) **120** and antenna **122**. The receiver includes an LNA **124**, a local oscillator **126**, a filter **128**, automatic gain control (AGC) **130** with an associated passband hardlimiter not separately shown, carrier recovery **132**, sampler **134**, clock recovery **136**, adaptive (or fixed) equalizer **138**, demodulator **140**, deinterleaver **142** and decoder **144**. With implementation of the present invention, several of the blocks shown in FIG. **1** are not required. These are the interleaver **112**, deinterleaver **142**, power amplifier **120**, automatic gain control **130** with passband hard-limiter, clock recovery **136** and carrier recovery **132**, and the equalizer **138**. It will now be explained how the proposed system obtains the omission of these blocks without impairing the quality and capacity of the system.

In this disclosure there will be described two systems as examples of the implementation of the invention. The system described first here will apply to a cellular system with a number of portable transceivers and base stations (BS). Then will be described a local area net-

work implementation. A local area network will typically be a system of equal transceivers. The invention may also be implemented with combinations of cellular and local area networks, or to a system with a number of equal transceivers and a master or controlling transceiver. "Equal" as used here means that the transceivers have more or less the same processing equipment and processing capabilities. The system described here is primarily for the exchange of voice information.

Link set-up and termination protocols between transceivers, and the equipment required to implement them, are well understood in the art as well as the basic structure of radio transceivers that may be used to implement the invention. Hence these elements are not described here. What is described here are the novel operational, functional and structural elements that constitute the invention.

Cellular Implementation of Wideband Modulation

The present invention proposes in one embodiment a wideband modulation scheme for exchange of information between transceivers such as portables and base stations.

Wideband in this patent document is described in the context of Wideband-Orthogonal Frequency Domain Modulation (W-OFDM or wideband OFDM). In OFDM, the entire available bandwidth B is divided into a number of points K, where adjacent points are separated by a frequency band Δf, that is $B=K\Delta f$. The K points are grouped into a frame of K_1 points and two tail slots of K_2 points each, so that $K=K_1+2K_2$. The frame carries the information intended for transmission under the form of multilevel differential phase shift keying (MDPSK) symbols or differential quadrature amplitude modulated (DQAM) symbols. Thus each point in the frame corresponds to one information symbol. The two tail slots act as guard bands to ensure that the out-of-band signal is below a certain power level. For example, when a pulse P(f) is selected for pulse shaping and the out-of-band signal has to be ydB or less relative to the in-band signal, K_2 is selected such that

$$20.\log_{10}|P(f)/P(0)| \leq y \text{ for } f \geq K_2\Delta f.$$

When the pulse is a raised-cosine pulse with a roll-off β and when the number of levels each symbol can take is M, the bit rate is equal to $K_1\log_2M/(\delta t+(1+\beta)/\Delta f)$ where $(1+\beta)/\Delta f$ is the duration of the frame and δt is the guard time required to take into account the delay of arrival and the delay spread due to multipath. In this case, the bandwidth efficiency, which is defined as the ratio between the bit rate and the bandwidth, is equal to:

$$\log_2M/((1+\beta+\delta t\Delta f)(1+2K_2/K_1))$$

In wideband-OFDM, both K and Δf are selected sufficiently large to achieve a high throughput as well as to reduce the effects on the BER of the clock error, the Doppler shift and the frequency offset between the LO in the transmitter and the one in the receiver. To show what is meant by "K and Δf are selected sufficiently large", consider the effect of increasing K and Δf on (1) the clock error, (2) the Doppler shift and (3) the frequency offset between the LO in the transmitter and the LO in the receiver.

(1) When a clock error at a transceiver of value τ occurs in the time domain, it causes a shift in the phase difference between adjacent symbols in the frequency domain of value $2\pi\Delta f\tau$. When τ is equal to χT where T is duration of one time domain sample and χ is any real value, the shift is equal to $2\pi\Delta f\chi T$. Hence, τ causes a shift in the phase difference between adjacent symbols of value $2\pi\chi/K_1$ since T is equal to $1/(K_1\Delta f)$. By doubling the number of symbols from K_1 to $2K_1$ the shift in the phase difference is reduced by half from $2\pi\chi/K_1$ to $\pi\chi/K_1$. Thus, the effect of the clock error on the BER is reduced by increasing K.

(2) When there is relative motion between the transmitting transceiver and the receiving transceiver, a Doppler shift occurs with a maximum absolute value $|V/\lambda|$ where V is the relative velocity between the two transceivers and λ is the wavelength of the travelling wave corresponding to the carrier frequency f_c (i.e. f_c is the frequency corresponding to the middle point in the frame). Such a Doppler shift causes a sampling error in the frequency domain of the same amount, or equivalently, it causes a sampling error of $V/(\lambda\Delta f)$ relative to one symbol sample. Thus, the effect of the Doppler shift on the BER is reduced by increasing Δf.

(3) When a frequency offset between the LO in the transmitter and the one in the receiver occurs with a value f_o, it causes a sampling error in the frequency domain of the same amount, or equivalently, it causes a sampling error of $f_o/\Delta f$ relative to one symbol sample. Thus, the effect on the BER of the frequency offset between the LO in transmitter and the one in the receiver is reduced by increasing Δf.

In summary, OFDM with a K and a Δf large enough to be able to achieve a specific throughput and large enough to be able to avoid using either a clock or a carrier recovery device without substantially affecting the BER is referred to here as Wideband-OFDM. As an example, let us assume that MDPSK is used in an OFDM system with the number M of levels, with a carrier frequency f_c, with a raised cosine pulse of roll-off β, with the LO at the receiver having a frequency offset f_o relative to the LO at the transmitter (so that the frequency offset between the carrier frequencies in the first and second transceivers of the multiplexed information is f_o), with a given maximum expected clock error $\tau=\chi T$ at the receiving transceiver, where T is the duration of one time domain sample, and with a maximum expected relative velocity V between the transceivers. Thus, in order to ensure that the out-of-band signal is ydB or less relative to the in-band signal and to be able to avoid using either a clock or a carrier recovery device without substantially affecting the BER we have to:

1. Find the acceptable sampling error $\Delta f'$, relative to one symbol sample, which does not substantially affect the BER. This can be done using the following rules:

$$\text{When } 0.2 \leq \beta \leq 0.3,\ \Delta f' = 7.50\%$$

$$\text{When } 0.3 \leq \beta \leq 0.4,\ \Delta f' = 10.0\%$$

$$\text{When } 0.4 \leq \beta \leq 0.5,\ \Delta f' = 12.5\%$$

$$\text{When } 0.5 \leq \beta \leq 0.6,\ \Delta f' = 15.0\%$$

2. Find Δf such that:

$$V/(\lambda\Delta f)+f_o/\Delta f \leq \Delta f'$$

3. Find K_2 such that

$$20 \log_{10}|P(f)/P(0)| \leq y \text{ for } f \geq K_2\sigma f$$

4. Find K_1 such that

$$2\pi\chi/K_1 < \pi/M$$

In this case, we refer to OFDM as Wideband-OFDM. Element 4 is a necessary condition for wideband OFDM, and given a sampling error, the sampling error may be corrected with the methods described in this patent document.

To implement wideband modulation, Orthogonal Frequency Division Multiplexing (OFDM) is preferred in which the information, for example encoded speech, is multiplexed over a number of contiguous frequency bands. Wideband OFDM forces the channel to be frequency selective and causes two types of linear distortion: amplitude distortion and phase distortion. To reduce the effect of amplitude distortion the modulation is preferably phase modulation, while the effect of phase distortion is reduced by employing differential phase modulation. Hence the modulation may be referred to as Differential OFDM (DOFDM). Unlike in other proposed schemes, neither pilot tones nor diversity are required in DOFDM. Possibly, quadrature amplitude modulation might be used, but amplitude modulation makes it difficult to equalize the distorting effects of the channel on the signal.

To implement wideband modulation in a cellular system with a plurality of portables and one or more base stations, a 100 MHz band is divided into 4096 points, as shown in FIG. 2, plus two tail slots of 195.3 KHz each. The 4096 points represent N voice channels (vc). Adjacent points are separated by 24.414 KHz and each point represents a Differential eight Phase Shift Keying (D8PSK) Symbol $e^{j\zeta(n)}$, where $\zeta(n)=\zeta(n-1)+\phi(n)+\chi(n)$. $\phi(n)$ takes one of the eight values $\{0, 2\pi/8, 4\pi/8, \ldots, 14\pi/8\}$ with equal probability for $n=1, 2, \ldots, 4096$ and $\phi(0)$ takes an arbitrary value. $X(n)$ also takes an arbitrary value. $\chi(n)$ may be used as a security key and will be known only to the transmitter and receiver. Information in the form of output bits from a vocoder are mapped onto $\phi(n)$. Vocoders are well known in the art and do not need to be described in detail here. The focus here is to transmit the bits with an acceptable Bit Error Rate, i.e. with a BER $\leq 10^{-2}$ for voice and $\leq 10^{-8}$ for data.

Ideally, 40.96 μs ($=1/24.414$ KHz) is the minimum duration required for one frame to be transmitted without frequency domain intersymbol interference. This can be achieved using a Raised Cosine (RC) pulse with zero roll-off, as shown in FIG. 3*a*. FIG. 3*a* illustrates a rectangular (time domain) window corresponding to the RC (frequency domain) pulse. Such a pulse, however, requires an infinite frequency band. To alleviate such a requirement, an RC pulse with a 20% roll-off (i.e. $\beta=0.2$) may be used as shown in FIG. 3*b*. The frame duration has increased by 20% to 49.152 μs. The two tail slots of 195.3 KHz each (i.e. 8 points each) ensure that the signal outside the entire band of 100.39 MHz is below -50 dB. To allow the frame to spread over the time as a consequence of the multipath nature of the channel, an excess frame duration of 2.848 μs is provided as shown in FIG. 3*c*, making the frame duration 52 μs in total.

Since the frame duration is 52 μs, the frame rate is 252 frames per 13.104 ms or equivalently, 126 full duplex frames may be transmitted/received every 13.104 ms. The reason for pre-selecting an interval of 13.104 ms is

to ensure a transmission delay to allow one transceiver to communicate with other transceivers at the same time, but must not be so long that the delay becomes unacceptable to the user. Delays longer than about 40 ms are too great for voice, and it is preferable to be lower. For data, the delay may be longer and still be acceptable.

In the exemplary embodiment described here, three bit rates are considered for the vocoder: 18.77 Kbps, 9.16 Kbps and 6.18 Kbps. Table I displays the structure of a vc slot and the number N of vc for each vocoder rate. The control symbols in each vc slot are required for handoff and power control. FIG. 2 shows that N vc can be transmitted simultaneously. This is known as Frequency Division Multiple Access. FIG. 3*c* shows that 126 full duplex frames can be transmitted every 13.104 ms in a Time Division Multiple Access fashion (TDMA). The total number of Full Duplex voice channels (FDvc) is therefore $126\times N$ and is shown in Table I.

To ensure that the channel is slowly fading, a Time Division Duplex protocol for exchange of information between the portable and the base station is proposed as illustrated in FIG. 4. The protocol is as follows:

1. The portable transmits a frame **410** over one vc slot. See the discussion in relation to FIG. 5*a* below.
2. The Base Station (BS) receives the frame **410** from the portable and processes (analyzes) it as shown and discussed in relation to FIG. 5*b* below.
3. Based on the received signal, the BS predistorts a frame **420** and transmits it to the portable over the same vc slot, 520 μs or some other suitable time interval later in which the channel does not change substantially. The time interval will depend on factors such as the frequency, speed of the transceiver and other environmental factors.
4. The portable receives the frame from the BS. See the discussion in relation to FIG. 5*c* below.
5. Steps 1 through 4 are repeated, as for example by the transmission of the next frame **430**, every 13.104 ms until the call is terminated.

During 520 μs, a portable travelling outdoor at 100 km/hr moves 1.44 cm, which leaves the outdoor channel largely unchanged. Indoors, a portable moving at 2 m/s moves 0.1 cm again leaving the channel unchanged. Assuming that the channel is reciprocal and stationary over 520 μs, a predistorted signal, transmitted by the BS, should reach the portable undistorted.

From FIG. 4, one can see that the portable transmits/receives one FDvc every 13.104 ms, while the BS can transmit/receive up to 21 frames or equivalently up to $21\times N$ FDvc every 13.104 ms. The frames **440** labelled frame **2** . . . frame **21** are frames that may be transmitted to other portables. This implies that while one BS is processing its data over 520 μs, six other BS can communicate to their corresponding portables in a Time Division Multiple Access (TDMA) fashion using the same frequency bands. Also, during the 13.104 ms, or such other preselected time interval that is suitable, the BS may communicate with one or more other portables.

When a portable is stationary during a call, it is possible with high probability to have the transmitted signal centered with several deep (frequency domain) nulls, hence, causing speech degradation. Also, narrowband interference over the vc slot can deteriorate the speech. In order to avoid both situations, the signal is preferably

frequency hopped into a new vc slot within the same (frequency domain) frame. This frequency hopping is ordered by the BS which is constantly monitoring the channel frequency response. Monitoring techniques, as well as frequency hopping, are known in the art, and not described here further. When an unacceptable speech degradation is first noticed by the BS a probation period is initiated and maintained for at least 10 cycles (i.e. 10×13.104 ms) unless speech degradation has ceased. In other words, the probation period is terminated if speech degradation has ceased. Frequency hopping is then ordered at the end of the probation period. The period of 10 cycles is long enough to indicate the portable stationarity and is short enough to allow speech interpolation between unacceptable speech frames, hence maintaining good speech quality. As known in the art, the BS ensures that no collisions take place between hopping portables.

Digital Signal Processing

The transmitter/receiver block diagrams corresponding to the protocol in FIG. 4 are shown in FIGS. 5*a*, 5*b* and 5*c*. FIG. 5*a* corresponds to step 1 in the protocol described above. Speech is provided to a vocoder **510** where the speech is digitized and coded to create bits of information. The bits are provided to the modulator **512** which turns them into D8PSK symbols, with three bits per symbol. The D8PSK symbols are then processed in the processor **514** which is described in more detail in FIG 6*a*. The output from the processor is then filtered in low pass filter **516**, upconverted to RF frequencies using local oscillator **518** and transmitted by antenna **520** Figure 5*b* corresponds to steps 2 and 3.

In FIG. 5*b*, the received signal at the base station is filtered in a bandpass filter **522**, and down converted by mixing with the output of a local oscillator **524**. The average power of the downcoverted signal is monitored by a power controller **525** that adjusts the average power to the specifications required by the sampler **526**. The adjusted downconverted bits are then sampled in sampler **526** to produce bits of information. The bits are then processed in the deprocessor **528**, described in more detail in FIG. 6*b*. An estimate of the phase differential of the received signal is taken in the channel estimator **530**, as described in more detail in relation to FIG. 7*a* and 7*b* below, and the estimated phase differential is supplied to a decoder-demodulator **532** to correct the received bits. The estimated phase differential is also supplied to a pre-distorter **534** in the transmitter. At the transmitter in the Base Station, the same blocks are incorporated as in the portable transmitter except that a pre-distorter is used to alter the phase of the D8PSK symbols to make the channel appear Gaussian (ideal) as opposed to a fading channel. The predistorter **534** receives a signal corresponding to the estimated phase differential of the channel. On the (believed reasonable) assumption that the channel is reciprocal, the signal being transmitted is predistorted with the estimated phase differential so that the received signal at the portable with which the BS is communicating will be corrected for any phase distortion over the channel. The advantage of rendering the channel Gaussian is a large saving in the power required to achieve an acceptable BER. The initial power control **525** also sends a signal to the pre-distorter **534** to adjust the transmitted power to an appropriate signal level for the sampler **526** in the portable's receiver depending on the average power of the received signal. Thus if the average power is too low, the transmitted power is increased and if the average power is too high, the transmitted power is decreased. The power controller **525** may also be used in frequency hopping to monitor the average power of the received frequency and determine when frequency hopping need take place.

FIG. 5*c* corresponds to step 4, and shows the receiver of the portable, which is the same as the receiver in the BS except it does not include an estimator or a power controller. These are not required in the portable on the assumption that the BS will carry out the phase estimation and the power control. However, if desired, the portable may include these functions.

FIGS. 6*a*, 6*b* and 6*c* illustrate the function and structure of the processor and the deprocessor respectively in the transmitter and receiver. Software for modelling the function of the processor in a general purpose computer has been filed with the Patent and Trademark Office as frames 3 to 26 of the microfiche appendix and for modelling the function of the deprocessor has been filed with the Patent and Trademark Office as frames 27-41 of the microfiche appendix.

FIG 6*a* shows that the processor is a DSP implementation of an RC pulse shaping filter with a 20% roll-off, followed by an inverse Fourier transform. The processor first inverse Fourier transforms the 4096 D8PSK modulated symbols output from the modulator. The transformed symbols are then triplicated as a group so that the total number of samples is tripled, with three consecutive groups each consisting of the 4096 transformed symbols. The triplication of the signal is illustrated in FIG. 6*c*, where the symbols are shown as first delayed and added together. Next, as shown in FIGS. 6*a* and 6*c*, the three groups are windowed by a Raised Cosine window with a roll-off of 0.2 centered in the middle of the three groups. In other words, the processor takes D8PSK symbols in, pulse shapes them and inverse Fourier transforms them. On the other hand, the deprocessor undoes what the processor did, i.e. it removes the pulse shaping, then Fourier transforms the received signal to obtain the original D8PSK symbols. The first two blocks in FIG. 6*b* are similar to the second two blocks in FIG. 6*a* except for two differences. The two differences are as follows. In the first block of the deprocessor, the repeated groups of symbols are partially overlapped as shown in FIG. 6*c* on the right hand side. In the second block, a rectangular window is used instead of the Raised Cosine. In the preferred implementation, the blocks are repeated three times but other numbers of repetition may be used.

FIGS. 6*a*, 6*b* and 6*c* show that the DSP blocks used in the processor are identical to the ones used in the deprocessor, except for a small change in the two transforms and a small change in the shapes of the two windows. Thus the same hardware can be used by both the processor and the deprocessor.

FIG. 7*a* shows a block diagram of an example of a preferred channel estimator, and FIG 7*b* is a flow chart showing the operation of the phase estimator. Each of the steps is carried out in a computing means that may be a special purpose computer or a general purpose computer programmed to carry out the digital signal processing described here, as for example with the software that has been filed with the Patent and Trademark Office as frames 42-55 of the microfiche appendix. Other methods of estimating the channel may be used that obtain an estimate of the channel group delay or

phase differential of the transmitted symbols. However, a preferred implementation is described here.

The first block in FIG. 7a estimates the envelope A(n) for n=1, . . . , 4096 of the (frequency domain) samples transmitted over the fading channel as output from the deprocessor. The estimate A'(n) is the square-root of the sum of the squares of the quadrature (Q) and inphase (I) samples output from the deprocessor which may be filtered in accordance with known techniques before or after estimation of the envelope. The second block performs the operation:

$\Delta \ln(A'(t)) = (\dot{A}'(t)) = (A'(n) - A'(n-1))/A'(n)$, for n=2, . . . , 4096, where A'(n) is the estimate of A(n). The third block performs a Hilbert transform operation $H[\Delta \ln(A'(t))]$ on the result of the second block. $H[\Delta \ln(A'(t))]$ is an estimate of $|\Delta\omega(n)|$ for n=2, . . . , 4096, where $\Delta\omega(n)$ is the phase differential of the transmitted signal (ω is the phase of the signal). The Hilbert transform is preferably carried out by taking the discrete fast Fourier transform of the data record, multiplying the positive frequency spectrum of the transform by $-i$ (square root -1), and the negative frequency spectrum of the transform by i, and taking the inverse discrete fast Fourier transform. The result is a set of symbols representing an estimate of the phase differential of the received signal, as determined from its sampled amplitude envelope.

Instead of a Hilbert transform, a different estimation may be made to estimate the phase differential. In this case, firstly, after the electromagnetic signal has been sampled, a series of data frames of a number of consecutive amplitude samples (A(t)) of the electromagnetic signal are constructed. These data frames are then segmented into segments $[t_1, t_2]$, where the amplitude of the electromagnetic signal is at least a predetermined number of dB less than its running mean, for example, 10dB. The following calculation is then applied to these segments of the amplitude samples:

$$\Delta\omega(t) \approx 1/t_0 \frac{-1}{1 + (t'/t_0)^2}$$

where $t' = t - t_{min}$, t_{min} is the time in $[t_1, t_2]$ when A(t) reaches its minimum, t is the time from the beginning of the segment, and t_0 is the time from the instant the amplitude of the electromagnetic signal reaches its minimum during the segment until the amplitude reaches double its minimum during the segment. In other words, the phase differential may be calculated from

$$\Delta\omega(t) \approx -t_0/(t_0^2 + t'^2).$$

The polarity of $\Delta\omega(n)$ is extracted using the last block shown in FIG. 7a. The estimate so calculated does not provide the sign of the differential. This may be determined by known techniques, for example by adding the phase differential to and subtracting the phase differential from the received phase ($\tan^{-1}$ (Q/I)) and taking the sign to be positive if the addition results in the smaller Euclidean distance to the expected value and negative if the subtraction results in the smaller Euclidean distance to the expected value.

Equivalently, for each sample n, the ideal phase closest to $\omega(n)+\Delta\omega(n)$ is determined and labelled $\omega_+(n)$, and the ideal phase closest to $\omega(n)-\Delta\omega(n)$ is determined and labelled $\omega_-(n)$. The two sums $P = \Sigma|\omega_+(n) - \{\omega(n)+\Delta\omega(n)\}|$ and $N = \Sigma|\omega\{\omega(n)-\Delta\omega(n)\}|$ are calculated. If P<N, then $\omega(n)+\Delta\omega(n)$ is used to correct the signal, and if not then $\omega(n)-\Delta\omega(n)$ is used to correct the signal.

For simplicity of the estimator, the determination of the sign need only be carried out for phase differentials greater than a predetermined threshold. This will be in the vicinity of a fade and may be accomplished by segmenting the data record into a segment in which the phase differential is larger than a selected threshold and setting the remainder of the data record to zero. This computation may be carried out with a simple discrimination circuit or equivalent computing means in the estimator.

The bias $\delta\omega$ of the channel group delay is estimated by averaging $\Delta\omega'(n)$ over n for n=1, . . . , 4096 where $\Delta\omega'(n)$ is the measured value of $\Delta\omega(n)$. The estimates A'(n) and $\Delta\omega'(n)$ are used directly in the predistortion filter in FIG. 5b, while the estimates $\Delta\omega(n)$ and $\delta\omega$ of the unbiased channel group delay and of the bias of the channel group delay respectively are used in the demodulator.

The complexity of the processor-deprocessor-channel estimator is displayed in Table II. Complexity is measured in Mega Instructions Per Second (MIPS) where one instruction is defined as one complex addition, one complex multiplication and a storage of one complex number. It does not include overhead.

The complexity of the processor-deprocessor-channel estimator in the BS is computed from the complexity of the Inverse Fast Fourier Transform (IFFT)/Fast Fourier Transform (FFT)/Hilbert Transform. The complexity is 4096×12×4×21/13.104 ms for the BS. For the portable, it is computed from the complexity of the FFT/IFFT per vc: (32×5+64+128+256+512+1024+2048+4096)2/13.104 ms for the portable with a 6.18 Kbps vocoder. Such a complexity assumes that the A/D converter operates at 100 MHz with 12 bit precision. As seen in Table II, the portable has smaller complexity due to the fact that the portable transmits/receives one vc in 13.104 ms and the BS transmits/receives up to 21×N vc in 13.104 ms.

Reducing Analog Complexity

Comparing FIG. 1 (prior art) and FIG. 5, it will be seen that several conventional blocks are not used in the present invention, namely the interleaver-deinterleaver, the Power Amplifier (PA), both the clock and the carrier recovery, both the AGC with its associated Pass-band hard limiter, as well as the equalizer.

From the BS point of view, the interleaver-deinterleaver is not required since the signal is predistorted before transmission forcing the received samples to be independent. From the portable point of view, the interleaver-deinterleaver is not required as a separate entity from the vocoder due to the fact that the channel is highly frequency selective, hence the interleaving/deinterleaving can be applied implicitly in the vocoder over one vc, without a need for a separate time domain interleaver/deinterleaver. This eliminates excess speech delays associated with interleaving/deinterleaving between frames.

The PA is not required since the cells can have, as shown later, a radius of up to at least 250 m outdoors and 30 m indoors, if the transmitted power is up to 6 dBm. Such a power can be generated by the Local Oscillator (LO) without a need for a PA. It is important to avoid using a PA since DOFDM generates a time

domain signal with non constant envelope. A power efficient class C PA cannot be used without distorting the signal. A class A PA can be used at the expense of power efficiency.

A clock recovery device is not required since a sampling error in the time domain is equivalent to a phase shift in the frequency domain. The phase shift is a linear function of frequency. It contributes to the bias in the channel group delay. Such a bias can be easily estimated and removed as mentioned previously by averaging $\omega'(n)$ over n in the frequency domain. Such an estimate is accurate as long as the sampling error is less than 0.2 μs or equivalently less than 20 samples (since in this case, the corresponding phase shift is less than π), and as long as the number of points in one vc is large enough as it is here.

A carrier recovery device is not required since a carrier offset in the time domain is equivalent to a sampling error in the frequency domain. For the chosen RC pulse, a sampling error of up to 10% of the duration of one pulse is acceptable.

This implies that a frequency offset of up to 2.414 KHz is acceptable regardless whether it is due to carrier offset as low as 1 part in a million, i.e. as low as 1 KHz per 1 GHz. When a carrier frequency higher than 2.414 GHz is required, one can decrease in FIG. 2 the number of points per 100 MHz or one can use an RC pulse with a rolloff larger than 20%.

Neither an AGC nor a Passband hard-limiter are required since the level of the received power may be controlled constantly. This is achieved as follows: The portable transmits a frame. The BS receives the frame and predistorts a frame intended for transmission accordingly, assuming that the channel is reciprocal and stationary over 520 μs. This includes controlling the transmitted power according to the received power. The BS transmits the predistorted frame and simultaneously orders the portable to control its power. The order is conveyed using the control symbol in the vc slot (See table I). The degree of power control may be determined using the power controller **525**, and the instruction for the inclusion of a power control symbol in the vc may be sent from the power controller **525** to the predistorter **534**.

One advantage of wideband modulation over narrowband modulation is that the wideband signal does not experience short term fading the same way the narrowband one does. The wideband signal is mainly affected by shadowing and other long term effects which vary slowly and are easily monitored from one frame to the other as long as the same vc slot is used by the portable to transmit and receive (i.e. as long as TDD is employed).

Finally, conventional equalization, whether it is linear or nonlinear, is not required simply because there is little or no ISI. Also, from the portable point of view, each received vc is predistorted by the BS. Hence, the channel can be modeled approximately as an ideal memoryless Additive White Noise Gaussian (AWGN) channel, assuming channel reciprocity and stationarity over 520 μs. From the BS point of view, since the received signal is not predistorted by the portable prior transmission, the channel estimator is used to reduce the effect of the channel group delay.

Smaller cells

As mentioned previously, the LO generates a 6 dBm average power, hence the signal power transmitted by the BS over one vc slot is (6 dBm $-10\log_{10}N$ dB) while the signal power transmitted by the portable over one vc slot is 0 dBm. Also, since the noise power over a 100 MHz band is -94 dBm, it is (-94 dBm $-10\log_{10}N$ dB) over one vc. A typical noise figure at the receiver is 7 dB. The penalty for not using a matched filter in the receiver is 1 dB. Combining together the above figures provides the portable with an (92 dB $-$ path loss in dB) received signal to noise ratio (SNR), while it provides the BS with an (86 dB $+10\log_{10}N$ dB $-$ path loss in dB) received SNR.

For a path loss of 75 dB, the radius of the urban cell can be 250 m while it can be 30 m for the indoor cell. Such a path loss provides the portable with a 17 dB received SNR, while it provides the BS with an (11 dB $+ 10\log_{10}N$ dB) received SNR. From the portable point of view, the channel can be modeled approximately as an ideal AWGN channel, hence the 17 dB received SNR results in a 2×10^{-3} BER. On the other hand, the channel can be pessimistically modeled as a Rayleigh fading channel from the BS point of view. The corresponding BER are displayed in Table III which shows that the achieved BER is $\leqq 4\times10^{-3}$. A BER $\leqq 10^{-2}$ is acceptable for voice.

Cell Pattern Reuse

From Table I, the number of Full Duplex voice channels (FDvc) that can be transmitted/received per frame is 136 over 100 MHz, for a 6.18 Kbps vocoder. If the bandwidth is halved to 50 MHz, the number of FDvc per frame is reduced to 68, the noise floor is reduced by 3 dB and the number of full duplex frames that a BS can transmit/receive is doubled to 42, leaving the frame duration, the number of frames per 13.104 ms and the processor/deprocessor complexity unchanged.

Reducing the available bandwidth directly affects the cell pattern reuse. This can be explained as follows, assuming that we are required to offer a minimum of 136 FDvc per cell, that the vocoder rate is 6.18 Kbps and that the cell radius is fixed at 250 m outdoors and 30 m indoors. For a 100 MHz band, we assign one frame per cell and offer 136 FDvc per cell. In this case, the cell pattern reuse consists of 126 cells as shown in FIG. 8*a* which displays a seven layer structure. For a 50 MHz band, we assign two frames per cell and offer 136 FDvc per cell, hence reducing our cell pattern reuse to a 63 cell pattern as shown in FIG. 8*b* which displays a five layer structure. If the available bandwidth is as low as 5.86 MHz, we have 8 vc per frame. Hence we have to assign 18 frames per cell in order to offer the minimum required number of FDvc per cell. This reduces the cell pattern reuse to as low as a 7 cell pattern as shown in FIG. 8*c* which displays a two layer structure.

In FIGS. 8*a*, *b* and *c*, a shaded area is shown around the center of the pattern, indicating 19, 38 and 126 full duplex frames that the central BS can transmit/receive respectively. Tables IVa, *b* and c show the number of cell layers in each cell pattern reuse, the coverage area in Km^2 of the pattern reuse for both the indoor and the urban environments, as well as the carrier to interference ratio (CIR) in dB, for the 100 MHz, 50 MHz and 5.96 MHz bands, respectively. In all cases, the CIR is large enough to sustain a toll quality speech.

Transmission/Reception Protocol

Since the number of FDvc a portable can transmit/receive is one, while the number of FDvc a BS can transmit/receive is much larger as shown in Table V for

each of the three vocoder rates, we have chosen the following transmission/reception protocol:

1. The portable transmits a frame over a vc.
2. Seven adjacent BS receive the frame from the portable.
3. One BS transmits to the portable, depending for example on the strength of the received signal by each of the BS.

The control of this protocol may use any of several known techniques. For example, the commonly used technique is to have the portable monitor the channel and determine which of several base stations it is closest to. It can then order the nearest BS to communicate with it. Another technique is to use a master control which receives information about the strength of the signal on the channel used by the portable and controls the BS accordingly. Such techniques in themselves are known and do not form part of the invention.

Such a protocol has several advantages. For instance, the location of the portable can be determined with high accuracy based on the received vc at the seven adjacent BS. Locating the portable can assist in the BS hand-off. A BS hand-off and a portable hand-off do not necessarily occur simultaneously, contrary to other prior art systems. In the present invention, when a portable roams from one cell X to an adjacent cell Y, a new vc is not required immediately. What is required is a BS hand-off, meaning that BS Y (associated with cell Y) must initiate transmission to the portable over the same vc, while the BS X (associated with cell X) must terminate its transmission to the portable.

A BS hand-off occurs without the knowledge of the portable and can occur several times before a portable hand-off is required. A portable hand-off is required only when the CIR is below a certain level. In this case, the Mobile Telephone Switching Office (not shown) calls for a portable hand-off in accordance with known procedures. Reducing the portable hand-off rate reduces the probability of dropped calls. This is because a dropped call occurs either because the portable hand-off is not successful or because there are no available channels in cell Y.

The present invention allows the use of post-detection diversity at the BS, and the use of dynamic channel allocation (DCA).

Dynamic Channel Allocation

DCA is made possible by each BS having capability to transmit/receive more than the number of FDvc allocated to its cell, namely seven times the number of FDvc for a 5.86 MHz band and up to twenty-one times the number of FDvc for a 100 MHz as well as a 50 MHz band. The DCA protocol simply consists of borrowing as many FDvc as needed from the adjacent cells, up to a certain limit. The limit for the case when we employ a 6.18 Kbps vocoder, a 5.86 MHz band and 18 frames per cell is obtained as follows. The cell reuse pattern consists of 7 cells. Each cell is preassigned 144 FDvc. Assuming that at peak hours, 75 FDvc are used on the average and 5 FDvc are reserved at all times, then we are left with 64 idle channels which represent the limit on the number of FDvc one can borrow from the cell.

One should distinguish between the limit on the channels borrowed and the limit on the nonpreassigned channels a BS can use. For instance, if a call originates in cell X and the portable roams into an adjacent cell Y where no preassigned cells are available, BS Y does not need to borrow immediately a new channel from an adjacent cell. It can use the original channel as long as the level of CIR is acceptable. If on the other hand, a portable wants to initiate a call in cell Y where all preassigned channels are used, BS Y can borrow a channel from an adjacent cell up to a limit of 64 channels per cell.

The main advantage of DCA over Fixed Channel Allocation (FCA) is the increase in traffic handling capability. For FCA, a 7 cell pattern each with a preassigned 144 Fdvc can carry a total traffic of 880.81 Erlang at 0.01 Blocking Probability (BP). For DCA, a 7 cell pattern consists of 6 cells each with 80 FDvc that can carry a total traffic of 392.17 Erlang, combined with one cell with 528 FDvc that can carry 501.74 Erlang. The total traffic is therefore 893.91 Erlang. This increase appears to be marginal (1.5%). However, if 501.74 Erlang are actually offered to one cell in the FCA system (with 14 FDvc/cell), while the six other cells carry 392.17/6=65.36 Erlang per cell, the BP at that busy cell 0.714 while it is negligible at the six other cells. The total blocked traffic (i.e. lost traffic) in the FCA system is then equal to ($6\times65.36\times0.0+1\times0.714\times501.24$) 358.24 Erlang. This represents a 0.4 average BP. If the DCA is allowed such a loss, its traffic handling capacity would increase to 1768.04 Erlang which represents a 100% increase in traffic handling capacity over the FCA system, or equivalently a 160% increase in the number of available FDvc. The DCA system thus represents a marked improvement over the FCA system.

Voice Activation

Voice activation is controlled by the BS according to techniques known in the art. At any instant during a conversation between a BS and a portable, there are four possibilities:

1. BS talks while the portable listens.
2. BS listens while the portable talks.
3. BS and portable talk simultaneously.
4. BS and portable listen simultaneously.

The BS controls the voice activation procedure by allocating in cases 1, 3 and 4 three slots (frames 1.1, 1.2 and 1.3) to the BS and one slot the portable (frame 1) every four slots as shown in FIG. 9*a*. Likewise up to 21 portables may communicate with the base station in like fashion.

In case 2, on receiving a signal from the portable, the BS allocates three slots (frames 1.1, 1.2 and 1.3) to the portable and one slot (frame 1) to the BS every four slots as shown in FIG. 9*b*. Likewise, up to 21 other portables may communicate with the base station in like fashion. Consequently, instead of transmitting two full duplex voice frames over four slots as in FIG. 4, voice activation allows us to transmit three full duplex voice frames over four slots. Hence, voice activation provides a 50% increase in the number of available FDvc at the expense of increasing DSP complexity.

Capacity

The capacity of Code Division Multiple Access (CDMA) may be defined as the number of half duplex voice channels (HDvc) effectively available over a 1.25 MHz band per cell. Based on such a definition, Table IV displays the capacity of analog FM and of the present system with a 6.18 Kbps vocoder, 5.86 MHz band, 1 frame per cell and DCA. As shown in Table IV, the capacity of analog FM is 6 HDvc/1.25 MHz/cell while for the present system it is 150 HDvc/1.25 MHz/cell.

The 6.25 MHz band consists of 5.86 MHz plus two tail slots. When voice activation is used, the capacity of the present system is increased by 1.5 times to 225 HDvc/1.25 MHz/cell, a 38 fold increase over analog FM.

Local Area Networks

The invention may also be applied to produce a 48 Mbps wireless LAN, which also satisfies the technical requirements for spread spectrum.

For wireless LAN, wideband differential orthogonal frequency division multiplexing is again employed. The LAN will incorporate a plurality of transceivers, all more or less equal in terms of processing complexity, and possibly with identical components except for addresses.

To implement wideband modulation for a LAN, a 26 MHz band is divided into 128 points, as shown in FIG. 10, plus two tail slots of 1.48 MHz each within the 26 MHz band. Adjacent points are separated by 180 KHz and each point, as with the application described above for a portable-base station, represents a D8PSK symbol. The transmitter components will be the same as shown in FIG. 5*b*, with suitable modifications as described in the following, and will include an encoder. The output bits from the encoder are mapped onto the D8PSK symbols.

The frame duration for the symbols is illustrated in FIG. 11. A rectangular time domain window corresponding to a RC frequency domain pulse has a 5.55 μs duration, and includes a 25% roll-off and excess frame duration of 0.26 μs, making a total 7.2 μs duration for the frame.

For such a wireless local area network (LAN), in which the transceivers are equal, the Time Division Duplex protocol is as illustrated in FIG. 12 (assuming there are at least a pair of transceivers):

1. A first transceiver transmits a signal (frame 0) over the entire frame.
2. A second transceiver receives the signal from the first transceiver and processes (analyzes) it.
3. Based on the received signal, the second transceiver predistorts and transmits nine frames (frames 1–9) to the first transceiver immediately.

Each transceiver has transmitter components similar to those illustrated in FIG. 5*b*, with suitable modifications to the internal structure to allow the use of the particular frequency band and frame duration employed.

The transmitter/receiver functional and structural block diagrams are shown in FIGS. 13*a*, 13*b* and 13*c* for the exchange of data. Data is provided to an encoder **810** where the data is digitized and coded to create bits of information. The bits are provided to the modulator **812** which turns them into D8PSK symbols, with three bits per symbol. The D8PSK symbols are then processed in the processor **814** which is described in more detail in FIG. 14*a*. The output from the processor is then filtered in low pass filter **816**, upconverted to RF frequencies using local oscillator **818** and transmitted by antenna **820**.

In FIG. 13*b*, the received signal at the base station is filtered in a bandpass filter **822**, and down converted by mixing with the output of a local oscillator **824**. The average power of the downcoverted signal is monitored by an initial power control **825** that adjusts the average power to the specifications required by the sampler **826**. The adjusted downconverted signal is then sampled in sampler **826** to produce bits of information. The bits are then processed in the deprocessor **828**, described in more detail in FIG. 14*b*. An estimate of the phase differential is taken in the channel estimator **830**, as described in more detail in relation to FIG. 7 above, and the estimated phase differential is supplied to a decoder/demodulator **832** to correct the received bits. The estimated phase differential is also supplied to a pre-distorter **834** in the transmitter. At the transmitter in the Base Station, the same blocks are incorporated as in the portable transmitter except that a pre-distorter is used to alter the envelope and phase of the D8PSK symbols to make the channel appear Gaussian (ideal) as opposed to a fading channel. The initial power control **825** also sends a signal to the pre-distorter **834** to adjust the transmitted power to an appropriate signal level for the sampler **826** in the first transceiver. It will be appreciated that a pre-distorter will be included in the first transceiver's transmitter but that it will not be operable, except when the first transceiver is operating as a base station.

FIG. 13*c* shows the functional blocks of the receiver of the first transceiver, which is the same as the receiver in the second transceiver except it does not include an estimator. The processor is illustrated in FIG. 14*a* and 14*c* and the deprocessor in FIG. 14*b* and 14*c*. The processor first inverse Fourier transforms the 128 D8PSK symbols output from the modulator. The transformed symbols are then triplicated as a group so that the total number of samples is tripled (see the left side of FIG. 4*c*), with three consecutive groups each consisting of the 128 transformed symbols. Next, the three groups are windowed by a Raised Cosine window with a roll-off of 0.25 centered in the middle of the three groups. In other words, the processor takes D8PSK symbols in, pulse shapes them and inverse Fourier transforms them. On the other hand, the deprocessor undoes what the processor did, i.e. it removes the pulse shaping, then Fourier transforms the received signal to obtain the original D8PSK symbols. The first two blocks in FIG. 14*b* are similar to the second two blocks in FIG. 14*a* except for two differences as follows. In the first block shown in FIG. 14*b*, the repeated groups of symbols are partially overlapped, as shown in FIG. 14*c*. In the second block, a rectangular window is used instead of the Raised Cosine to produce 128 output samples corresponding to the 416 input samples.

The phase estimator is the same as that shown in FIG. 7, except that there are only 128 input samples, and the same description applies.

For both the LAN and cellular networks, the present system is designed to operate as a spread spectrum system preferably over such bands as are permitted, which at present are the 902–928 MHz band, 2.4–2.4835 GHz and 5.725–5.85 MHz. The carrier frequency in the local oscillator shown in FIGS. 5*a*, *b* and *c* will then be 915 MHz in the case of the 902–928 MHz band, and the frequencies used for modulation will be centered on this carrier frequency.

Alternative Embodiments

A person skilled in the art could make immaterial modifications to the invention described and claimed in this patent without departing from the essence of the invention.

For example, a system may consist of one or more central controllers (comparable to the Base Stations in the exemplary cellular system described) and some

slave units (comparable to the portables). The slave unit executes the commands it receives from the central controller. The commands may be requesting the slave unit to transmit a receive acknowledge, a status code or information that the slave has access to. The command may also be to relay the command or the information to another slave unit.

We claim:

1. A transceiver including a transmitter for transmitting electromagnetic signals and a receiver for receiving electromagnetic signals having amplitude and phase differential characteristics, the transmitter comprising:

an encoder for encoding information;

a wideband frequency division multiplexer or multiplexing the information onto wideband frequency channels;

a low pass filter;

a local oscillator for upconverting the multiplexed information for transmission;

a processor for applying a fourier transform to the multiplexed information to bring the information into the time domain for transmission;

further including, in the receiver of the transceiver;

a bandpass filter for filtering the received electromagnetic signals;

a local oscillator for downconverting the received electromagnetic signals to produce output;

a sampler for sampling the output of the local oscillator to produce sampled signals to the channel estimator;

a channel estimator for estimating one or both of the amplitude and the phase differential of the received signals to produce as output one or both of an estimated amplitude and an estimated phase differential respectively; and

a decoder for producing signals from the sampled signals and the output from the channel estimator.

2. The transceiver of claim 1 further including, in the receiver of the transceiver:

a deprocessor for applying an inverse Fourier transform to the samples output from the sampler.

3. The transceiver of claim 2 further including, in the receiver of the transceiver:

a power controller before the sampler for monitoring the power of the received signal and for controlling the power of the signal

4. The transceiver of claim 3 further including, in the transmitter of the transceiver:

a pre-distorter before the processor, the pre-distorter being connected to the channel estimator, for pre-distorting a signal to be transmitted with one or both of the estimated amplitude or the estimated phase differential.

5. The transceiver of claim 4 in which the power controller is also connected to the pre-distorter for controlling the power of the signal to be transmitted.

6. The transceiver of claim 1 further including: means to modify the received signal with one or both of the estimated amplitude and phase differential respectively.

7. A method for allowing a number of wireless transceiver to exchange frames of information, the method comprising the steps of:

multiplexing a first frame of information over a number of frequencies within a frequency band at a first transceiver to produce multiplexed information;

processing the multiplexed information at the first transceiver,

transmitting the processed information to a second transceiver using a carrier frequency fc;

receiving the processed information at the second transceiver; and

processing the processed information at the second transceiver during a first time interval;

in which the frequency band is formed from a first set of K1 points and a pair of tall slots each having K2 points, each of the points being separated by a frequency range of Δf, the second transceiver has a maximum expected clock error χT, where T is the duration of one time domain sample, the information is multiplexed over a number M of levels, and K1 selected such that $2\pi\chi/K1<\pi/M$, whereby the width of the frequency band is chosen so that neither carrier nor clock recovery is required at the second transceiver.

8. The method claim 7 further including transmitting a second frame of information from the second transceiver to the first transceiver within the same frequency band.

9. The method of claim 7 in which K2 is selected so that the out of band signal is less than a given level.

10. The method of claim 7 in which the first and second transceivers have an expected maximum relative velocity V, the first and second transceivers have carrier frequencies with a frequency offset from each other of of' the carrier frequency has a corresponding travelling wavelength λ and Δf is selected so that $[V/(\lambda\Delta f)+of/\Delta f]$ is less than or equal to a preselected sampling error.

11. The method of claim 7 in which processing the multiplexed information at the second transceiver further includes calculating the mean of the phase shift due to sampling error by summing an estimated phase differential of the received signal.

12 The method of claim 11 in which the mean of the phase shift due to sampling error is divided by K1 and the result removed from the phase differential of the received signal.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,282,222
DATED : January 25, 1994
INVENTOR(S) : M. Fattouche et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

<u>Column 19,</u>
Line 14, "or" should read -- for --
Line 21, "fourier" should read -- Fourier --
Line 24, "transceiver;" should read -- transceiver: --

<u>Column 20,</u>
Line 8, "transceiver" should read -- transceivers --
Line 14, "transceiver," should read -- transceiver; --
Line 22, "tall slots" should read -- tail slots --
Line 42, "of of' the" should read -- of fo, the --
Line 44, "+of/Δf]" should read -- +fo/Δf] --

Signed and Sealed this

Eighteenth Day of September, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office

Case 3:07-cv-06274-SI Document 41-4 Filed 01/31/2008 Page 5 of 39

EXHIBIT B

US00RE37802E

(19) **United States**

(12) **Reissued Patent**

Fattouche et al.

(10) **Patent Number: US RE37,802 E**

(45) **Date of Reissued Patent: Jul. 23, 2002**

(54) **MULTICODE DIRECT SEQUENCE SPREAD SPECTRUM**

(75) Inventors: **Michel T. Fattouche; Hatim Zaghloul**, both of Calgary (CA)

(73) Assignee: **Wi-LAN Inc.**, Calgary (CA)

(21) Appl. No.: **09/151,604**

(22) Filed: **Sep. 10, 1998**

Related U.S. Patent Documents

Reissue of:

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Appl. No.: **08/186,784**
Filed: **Jan. 24, 1994**

(51) **Int. Cl.**^{7} **H04B 1/707**; H04B 1/69

(52) **U.S. Cl.** **375/141**; 370/209; 375/146; 375/147; 380/34

(58) **Field of Search** 375/200, 201, 375/202, 203, 204, 206, 207, 208, 209, 210, 130–153, 271, 279, 280, 322, 329, 332; 380/34, 46; 370/203, 204, 205, 206, 207, 208, 209, 210, 211; 364/717.01, 717.02, 717.03, 717.04, 717.05, 717.06, 717.07; 331/78; 714/746, 752, 778, 781, 782

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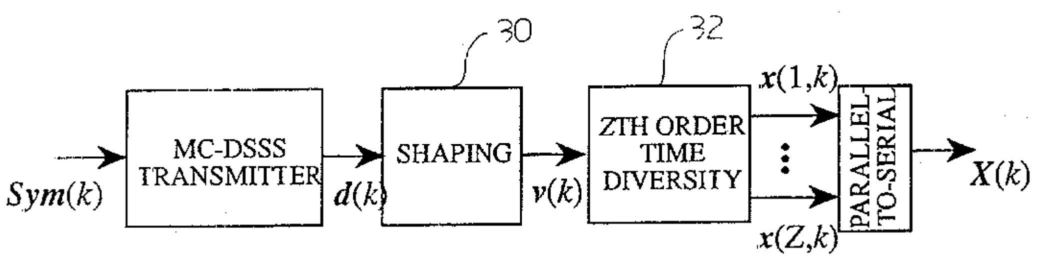
(57) **ABSTRACT**

In this patent, we present MultiCode Direct Sequence Spread Spectrum (MC-DSSS) which is a modulation scheme that assigns up to N DSSS codes to an individual user where N is the number of chips per DSSS code. When viewed as DSSS, MC-DSSS requires up to N correlators (or equivalently up to N Matched Filters) at the receiver with a complexity of the order of N^2 operations. In addition, a non ideal communication channel can cause InterCode Interference (ICI), i.e., interference between the N DSSS codes. In this patent, we introduce new DSSS codes, which we refer to as the "MC" codes. Such codes allow the information in a MC-DSSS signal to be decoded in a sequence of low complexity parallel operations which reduce the ICI. In addition to low complexity decoding and reduced ICI, MC-DSSS using the MC codes has the following advantages: (1) it does not require the stringent synchronization DSSS requires, (2) it does not require the stringent carrier recovery DSSS requires and (3) it is spectrally efficient.

40 Claims, 20 Drawing Sheets



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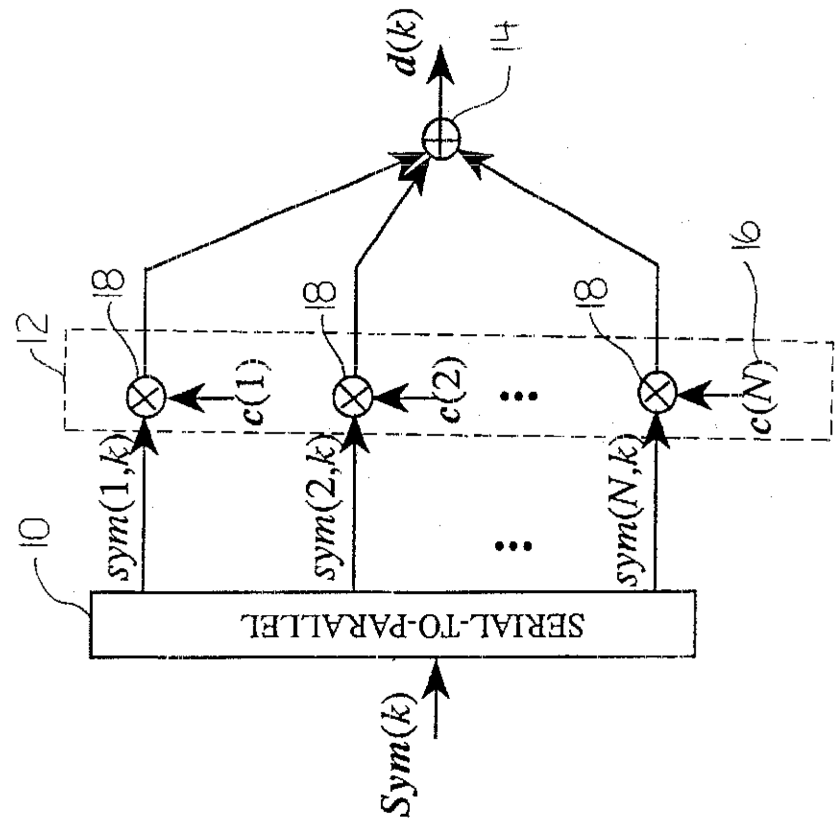
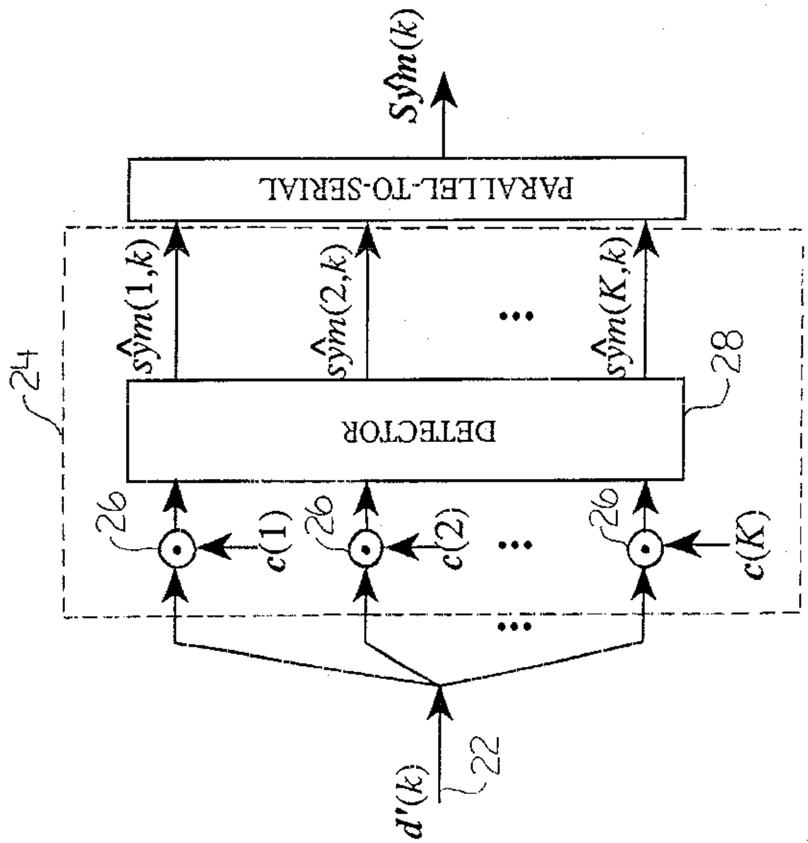
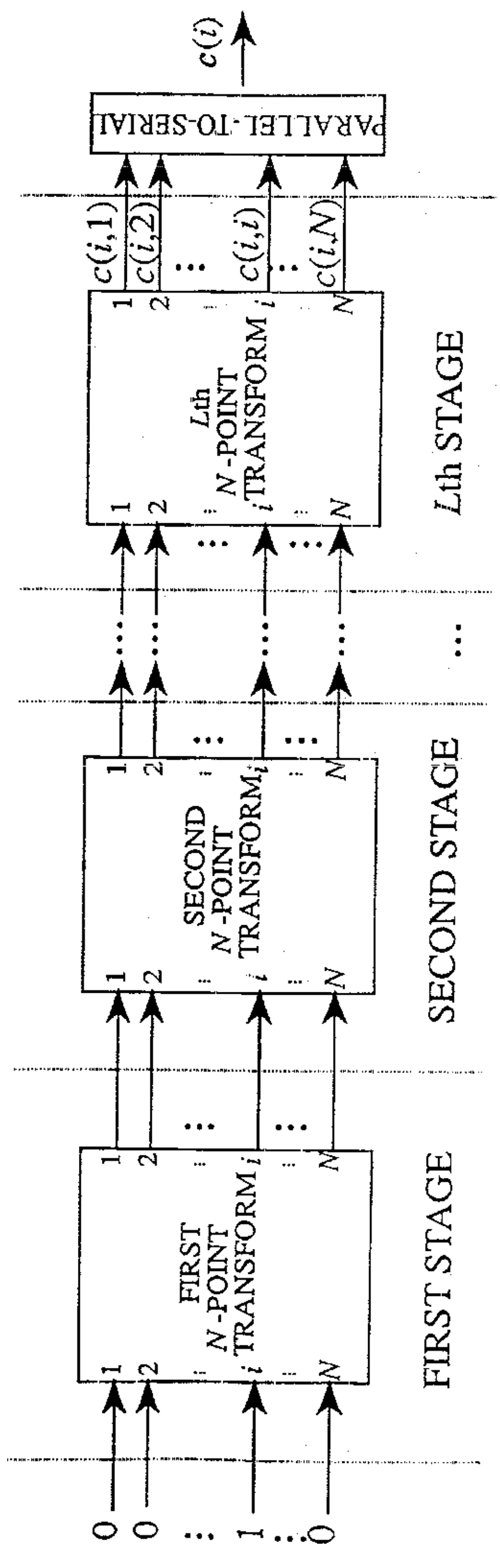

d(k)
14
12
18
16
c(1)
c(2)
c(N)
sym(1,k)
sym(2,k)
sym(N,k)
10
SERIAL-TO-PARALLEL
Sym(k)

FIGURE 1



PARALLEL-TO-SERIAL
DETECTOR
$\hat{Sym}(k)$
$\hat{sym}(1,k)$
$\hat{sym}(2,k)$
$\hat{sym}(K,k)$
$c(1)$
$c(2)$
$c(K)$
$d'(k)$
22
24
26
28

FIGURE 2



c(i)
PARALLEL-TO-SERIAL
c(i,1) c(i,2) ... c(i,i) ... c(i,N)
Lth N-POINT TRANSFORM
Lth STAGE
SECOND N-POINT TRANSFORM
SECOND STAGE
FIRST N-POINT TRANSFORM
FIRST STAGE
0 0 ... 1 ... 0

FIGURE 3

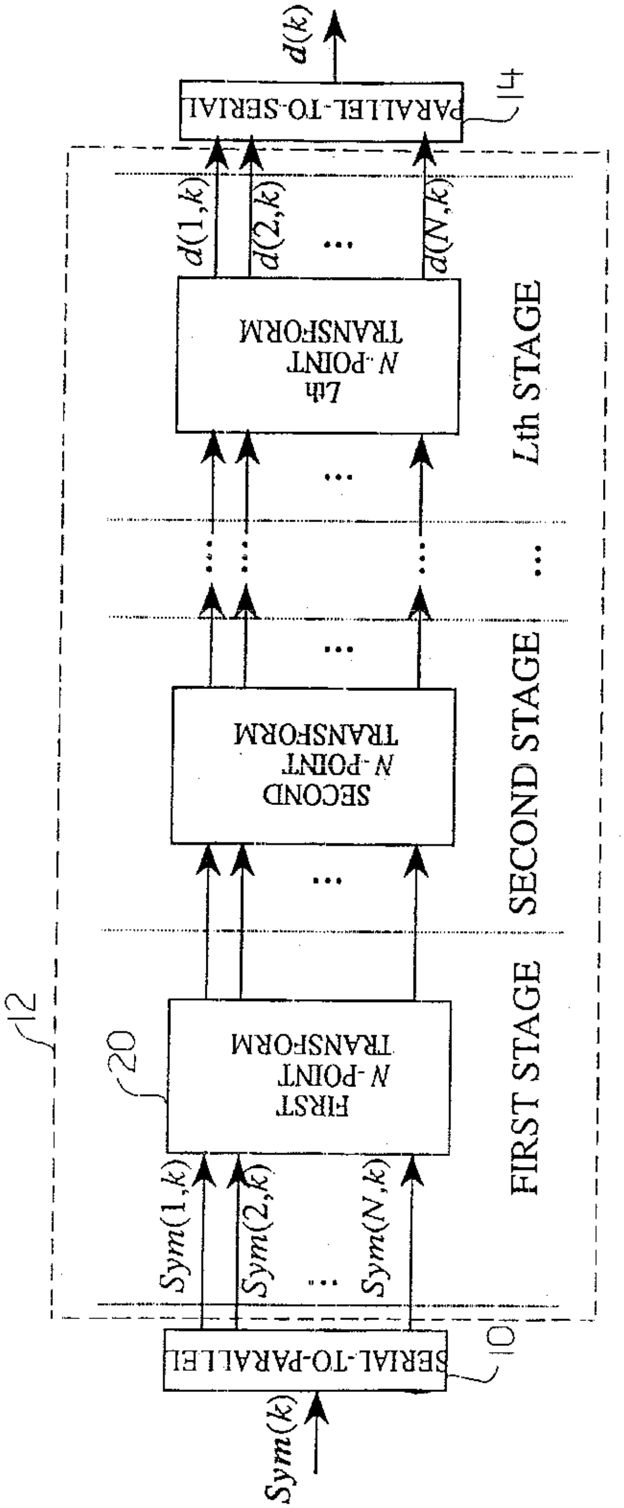
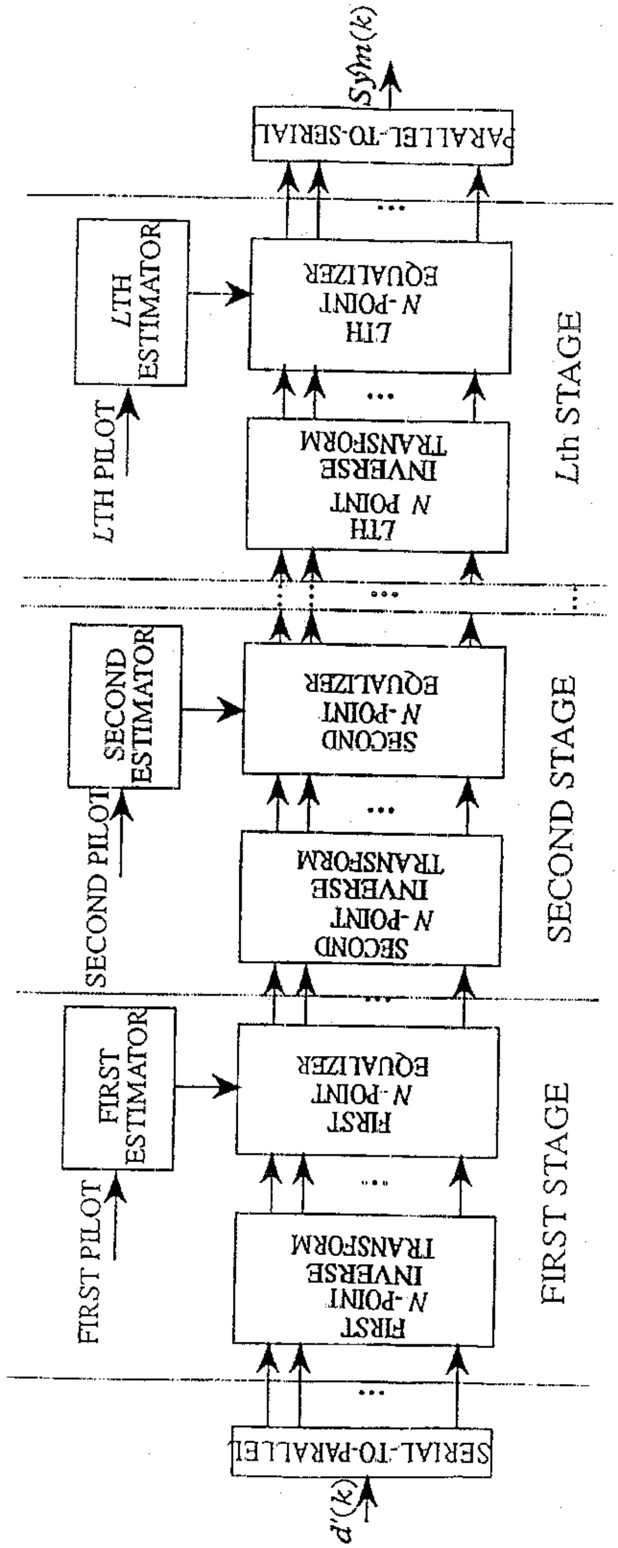
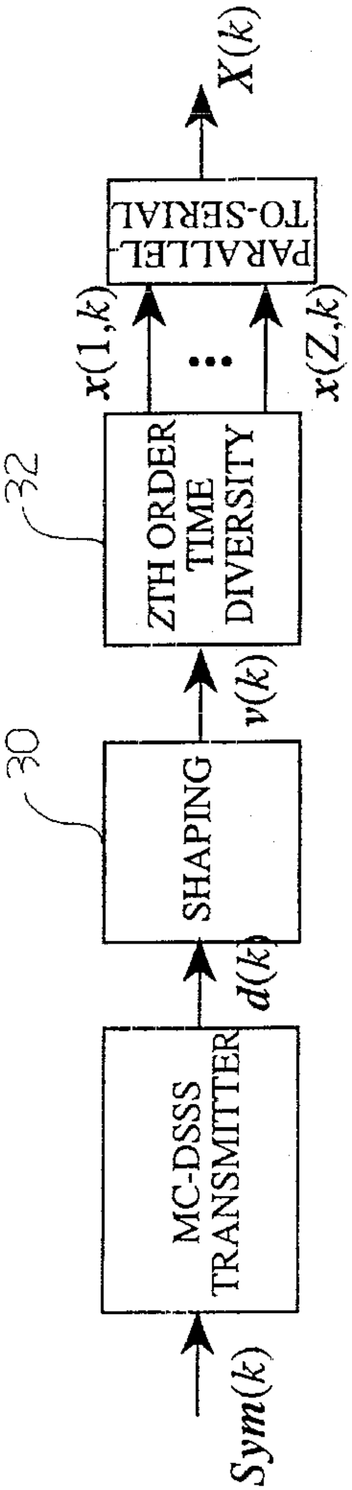

Sym(k)
SERIAL-TO-PARALLEL
10
12
Sym(1,k)
Sym(2,k)
Sym(N,k)
20
FIRST N-POINT TRANSFORM
FIRST STAGE
SECOND N-POINT TRANSFORM
SECOND STAGE
Lth N-POINT TRANSFORM
Lth STAGE
d(1,k)
d(2,k)
d(N,k)
PARALLEL-TO-SERIAL
14
d(k)

FIGURE 4



$d'(k)$
SERIAL-TO-PARALLEL
FIRST PILOT
FIRST ESTIMATOR
FIRST N-POINT INVERSE TRANSFORM
FIRST N-POINT EQUALIZER
FIRST STAGE
SECOND PILOT
SECOND ESTIMATOR
SECOND N-POINT INVERSE TRANSFORM
SECOND N-POINT EQUALIZER
SECOND STAGE
LTH PILOT
LTH ESTIMATOR
LTH N POINT INVERSE TRANSFORM
LTH N-POINT EQUALIZER
Lth STAGE
PARALLEL-TO-SERIAL
$Sym(k)$

FIGURE 5



Sym(k)
MC-DSSS TRANSMITTER
d(k)
30
SHAPING
v(k)
32
ZTH ORDER TIME DIVERSITY
x(1,k)
x(Z,k)
PARALLEL-TO-SERIAL
X(k)

FIGURE 6

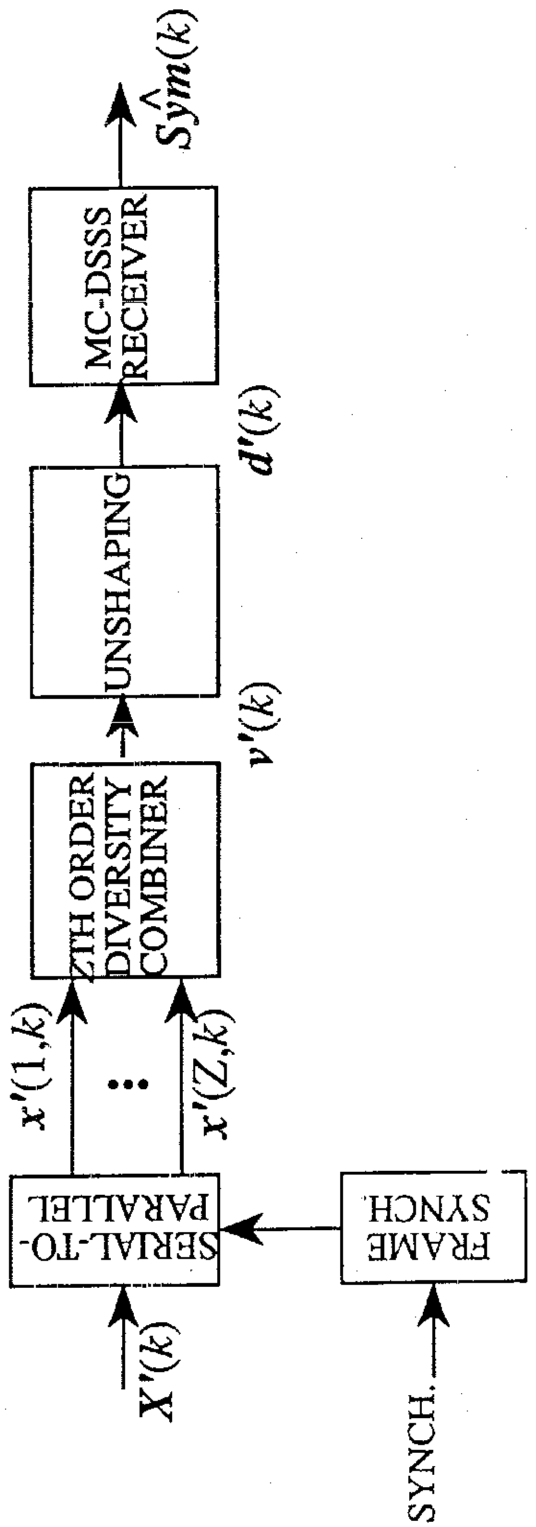

X'(k)
SERIAL-TO-PARALLEL
SYNCH.
FRAME SYNCH
x'(1,k)
x'(Z,k)
ZTH ORDER DIVERSITY COMBINER
v'(k)
UNSHAPING
d'(k)
MC-DSSS RECEIVER
Sym^(k)

FIGURE 7

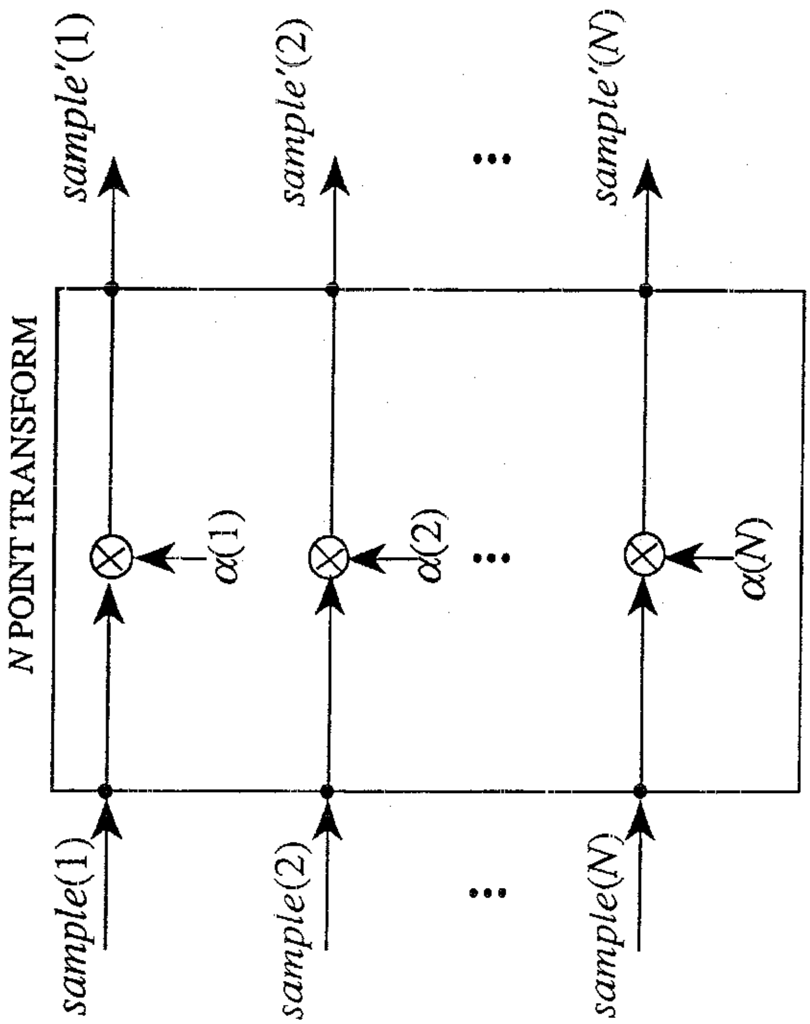

N POINT TRANSFORM
sample(1)
sample(2)
sample(N)
α(1)
α(2)
α(N)
sample'(1)
sample'(2)
sample'(N)

FIGURE 8

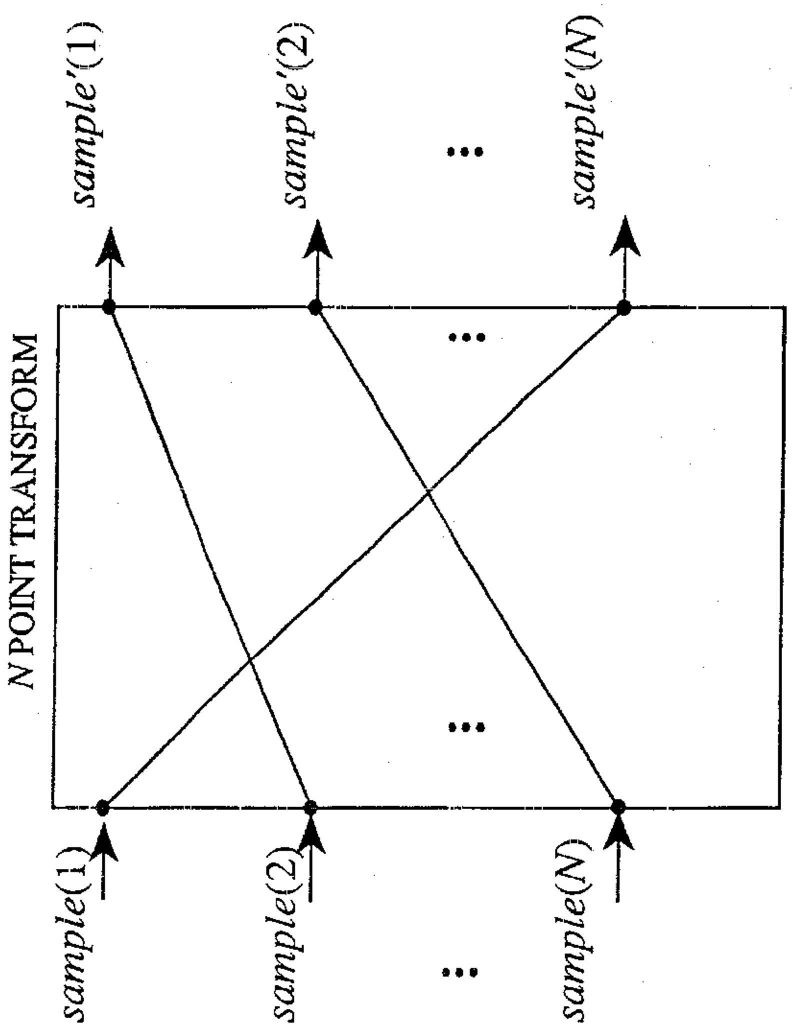

N POINT TRANSFORM
sample'(1)
sample'(2)
...
sample'(N)
sample(1)
sample(2)
...
sample(N)

FIGURE 9

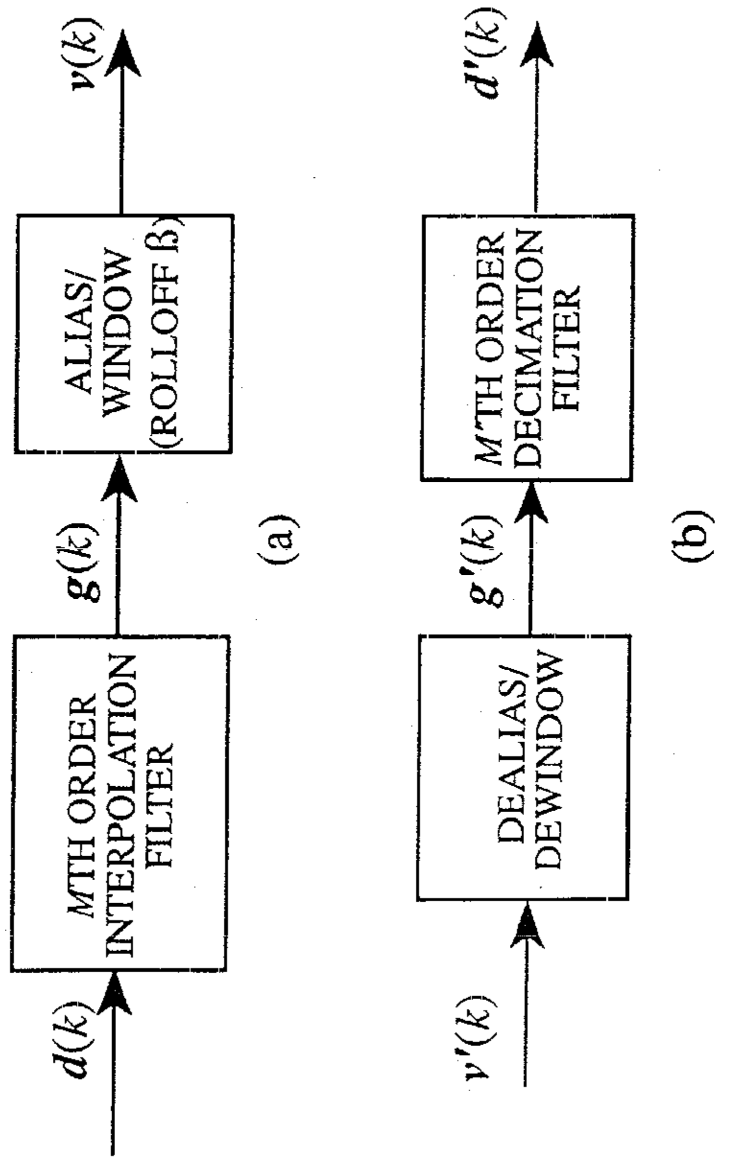

d(k)
MTH ORDER
INTERPOLATION
FILTER
g(k)
ALIAS/
WINDOW
(ROLLOFF ß)
v(k)
(a)
v'(k)
DEALIAS/
DEWINDOW
g'(k)
MTH ORDER
DECIMATION
FILTER
d'(k)
(b)

FIGURE 10

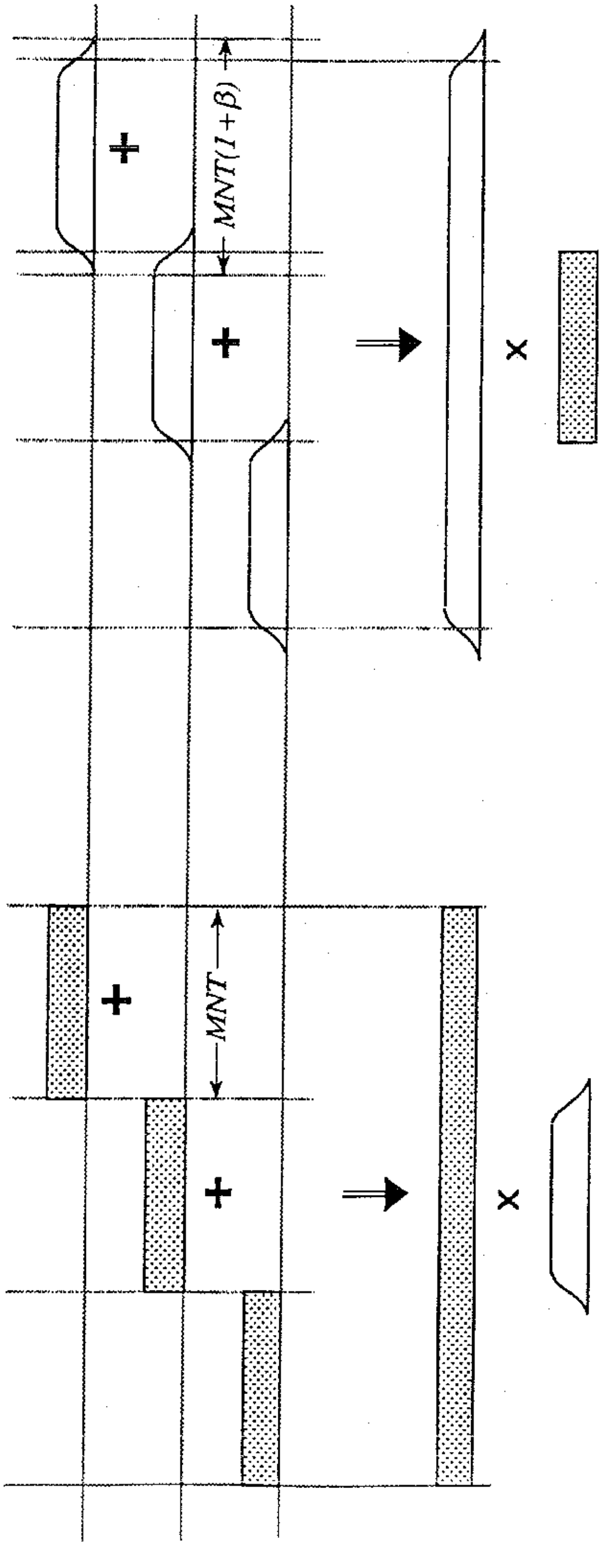


FIGURE 11

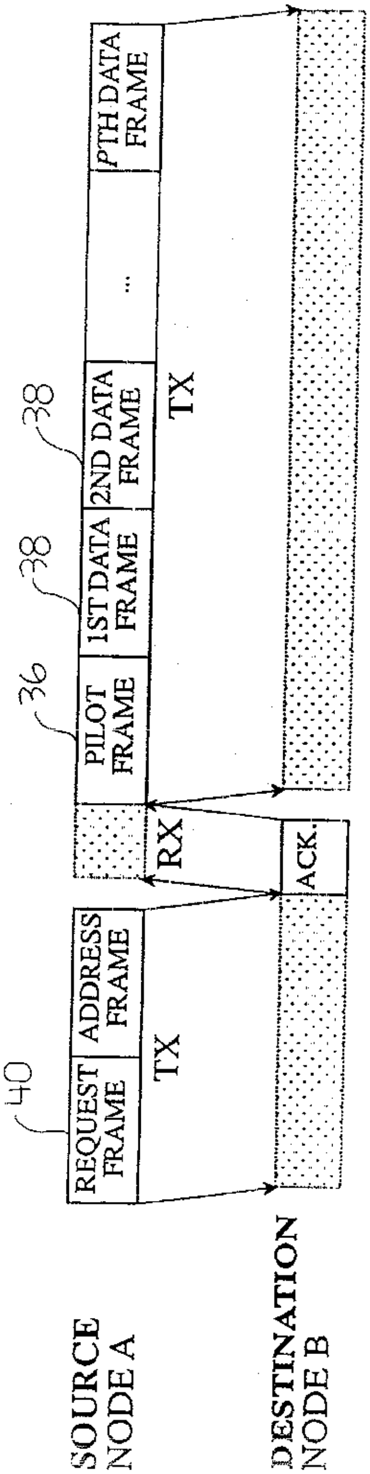

SOURCE NODE A
DESTINATION NODE B
40
REQUEST FRAME
ADDRESS FRAME
TX
RX
ACK.
36
PILOT FRAME
38
1ST DATA FRAME
38
2ND DATA FRAME
...
PTH DATA FRAME
TX

FIGURE 12

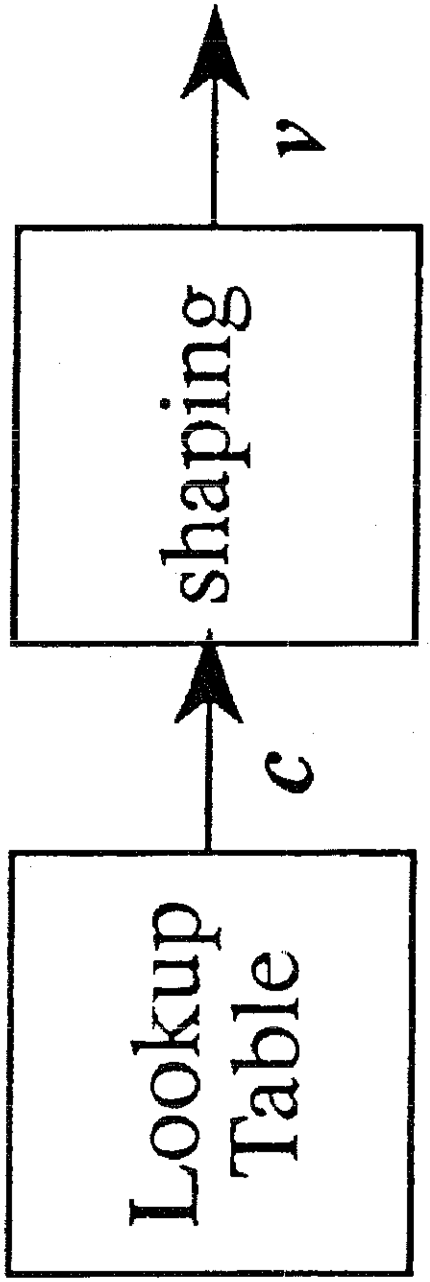


FIGURE 13

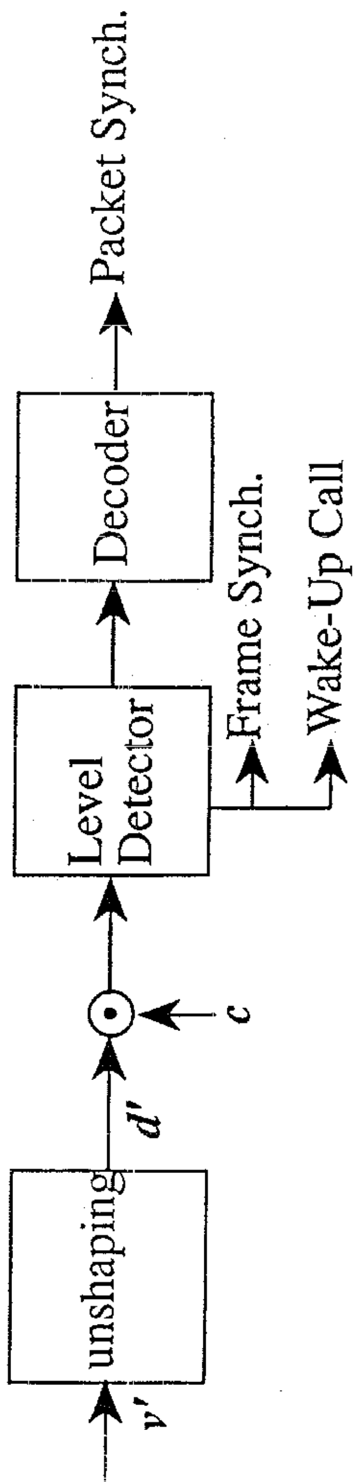

Packet Synch.
Decoder
Frame Synch.
Wake-Up Call
Level Detector
c
d'
unshaping
v'

FIGURE 14

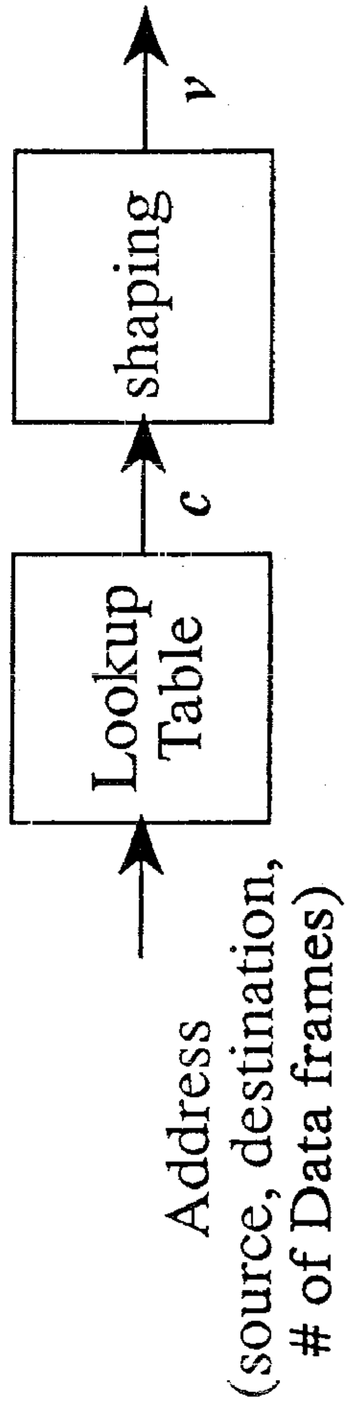

Address
(source, destination,
# of Data frames)
Lookup
Table
c
shaping
v

FIGURE 15

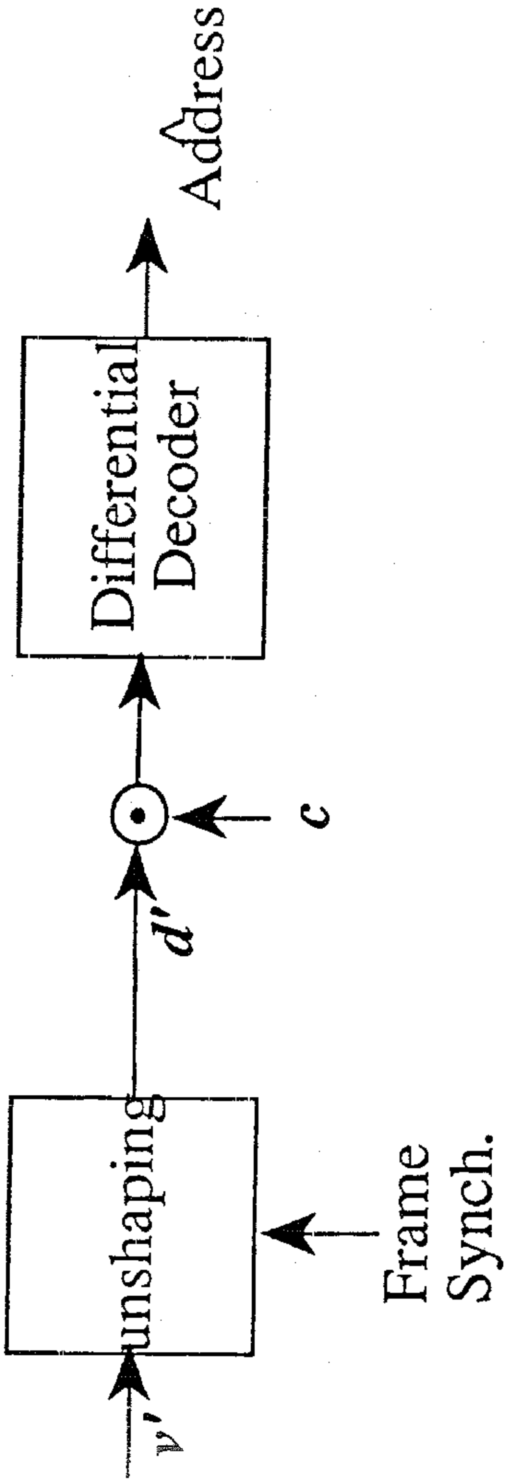


FIGURE 16

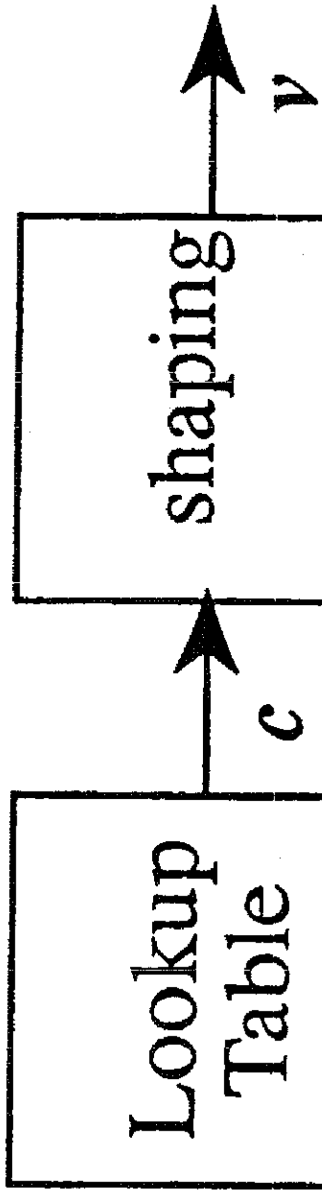


FIGURE 17

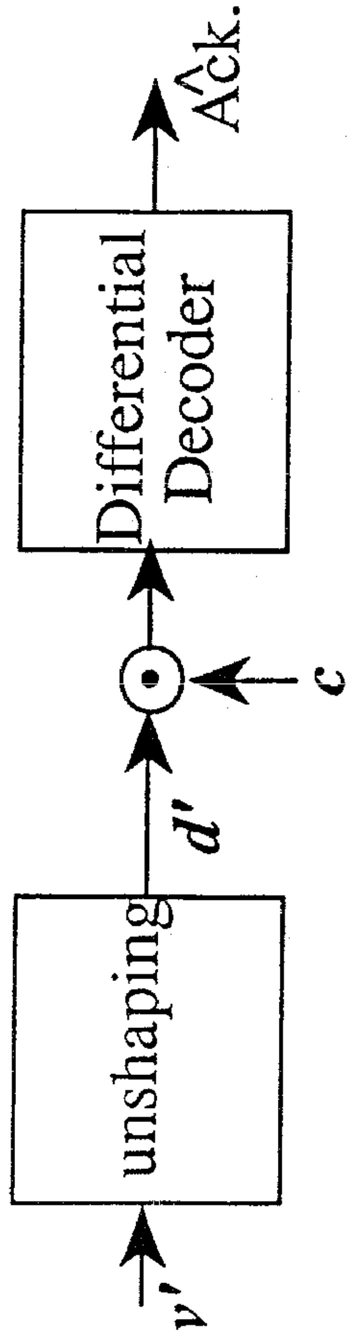


FIGURE 18

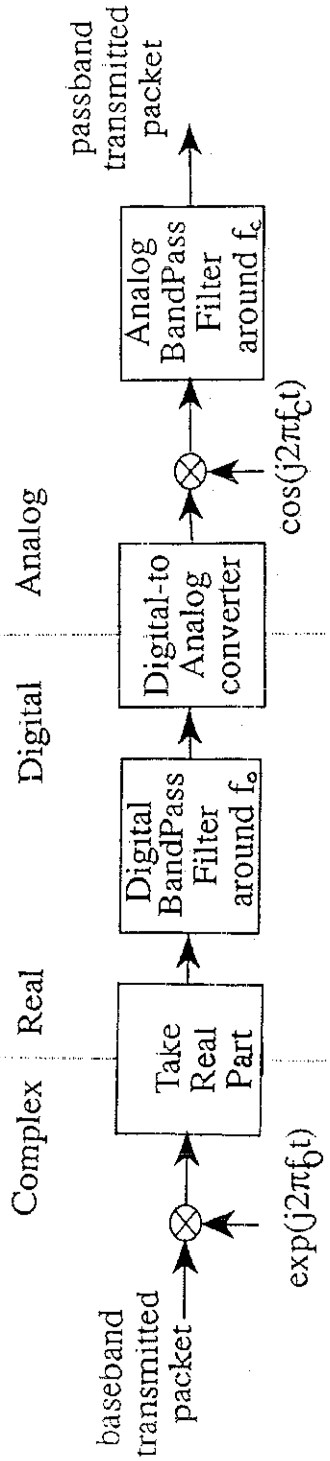

baseband transmitted packet
$\exp(j2\pi f_0 t)$
Complex
Real
Take Real Part
Digital BandPass Filter around f_o
Digital
Analog
Digital-to Analog converter
$\cos(j2\pi f_c t)$
Analog BandPass Filter around f_c
passband transmitted packet

FIGURE 19

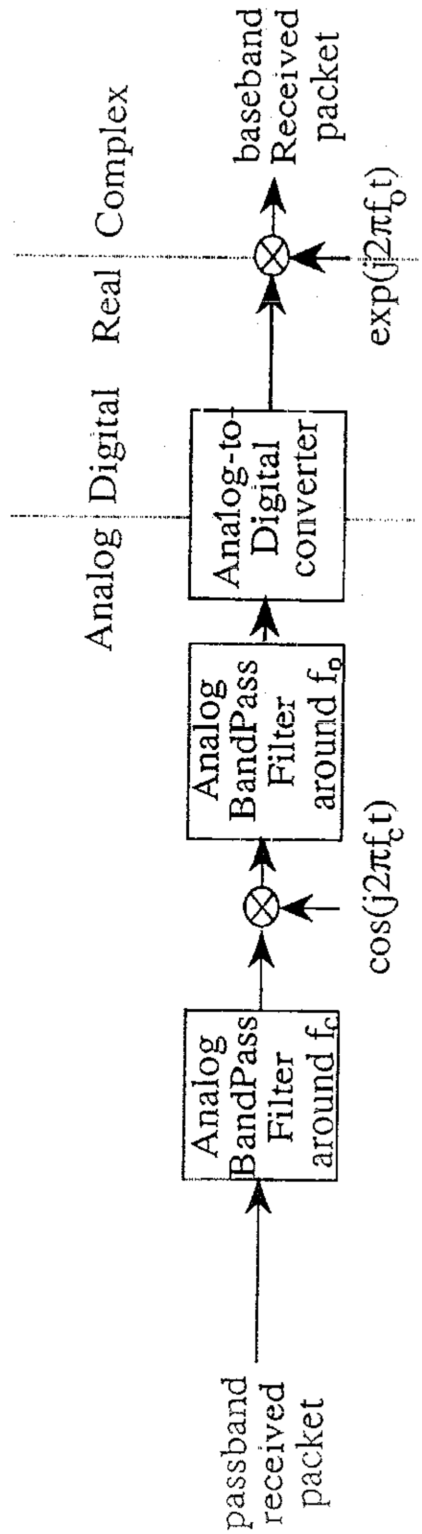

passband received packet
Analog BandPass Filter around f_c
$\cos(j2\pi f_c t)$
Analog BandPass Filter around f_o
Analog-to-Digital converter
$\exp(j2\pi f_o t)$
baseband Received packet
Analog
Digital
Real
Complex

FIGURE 20

MULTICODE DIRECT SEQUENCE SPREAD SPECTRUM

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This application is a REISSUE of Ser. No. 08/186,784 filed Jan 24, 1994 is a continuation-in-part of U S application Ser. No 07/861,725 filed Mar. 31, 1992, now U.S Pat. No. 5,282,222, the benefit of the filing date of which is hereby claimed under 35 U S C. §120.

FIELD OF THE INVENTION

The invention deals with the field of multiple access communications using Spread Spectrum modulation Multiple access can be classified as either random access, polling, TDMA, FDMA, CDMA or any combination thereof Spread Spectrum can be classified as Direct Sequence, Frequency-Hopping or a combination of the two

BACKGROUND OF THE INVENTION

Commonly used spread spectrum techniques are Direct Sequence Spread Spectrum (DSSS) and Code Division Multiple Access (CDMA) as explained in Chapter 8 of "Digital Communication" by J G. Proakis, Second Edition, 1991, McGraw Hill, DSSS is a communication scheme in which information bits are spread over code bits (generally called chips). It is customary to use noise-like codes called pseudo random noise (PN) sequences. These PN sequences have the property that their auto-correlation is almost a delta function and their cross-correlation with other codes is almost null The advantages of this information spreading are:

1. The transmitted signal can be buried in noise and thus has a low probability of intercept.
2. The receiver can recover the signal from interferers (such as other transmitted codes) with a jamming margin that is proportional to the spreading code length
3. DSSS codes of duration longer than the delay spread of the propagation channel can lead to multipath diversity implementable using a Rake receiver.
4. The FCC and the DOC have allowed the use of unlicensed low power DSSS systems of code lengths greater than or equal to 10 in some frequency bands (the ISM bands)

It is the last advantage (i.e., advantage 4 above) that has given much interest recently to DSSS

An obvious limitation of DSSS systems is the limited throughput they can offer In any given bandwidth, B, a code of length N will reduce the effective bandwidth to B/N To increase the overall bandwidth efficiency, system designers introduced Code Division Multiple Access (CDMA) where multiple DSSS communication links can be established simultaneously over the same frequency band provided each link uses a unique code that is noise-like. CDMA problems are:

1. The near-far problem: a transmitter "near" the receiver sending a different code than the receiver's desired code produces in the receiver a signal comparable with that of a "far" transmitter sending the desired code
2. Synchronization of the receiver and the transmitter is complex (especially) if the receiver does not know in advance which code is being transmitted.

SUMMARY OF THE INVENTION

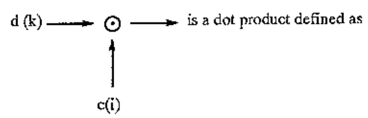
We have recognized that low power DSSS systems complying with the FCC and the DOC regulations for the ISM bands would be ideal communicators provided the problems of CDMA could be resolved and the throughput could be enhanced. To enhance the throughput, we allow a single link (i.e., a single transceiver) to use more than one code at the same time. To avoid the near-far problem only one transceiver transmits at a time In this patent, we present Multi-Code Direct Sequence Spread Spectrum (MC-DSSS) which is a modulation scheme that assigns up to N codes to an individual transceiver where N is the number of chips per DSSS code. When viewed as DSSS, MC-DSSS requires up to N correlators (or equivalently up to N Matched Filters) at the receiver with a complexity of the order of N^2 operations. When N is large, this complexity is prohibitive In addition, a nonideal communication channel can cause InterCode Interference (ICI), i.e., interference between the N DSSS codes at the receiver. In this patent, we introduce new codes, which we refer to as "MC" codes. Such codes allow the information in a MC-DSSS signal to be decoded in a sequence of low complexity parallel operations while reducing the ICI In addition to low complexity decoding and ICI reduction, our implementation of MC-DSSS using the MC codes has the following advantages:

1. It does not require the stringent synchronization DSSS requires Conventional DSSS systems requires synchronization to within a fraction of a chip whereas MC-DSSS using the MC codes requires synchronization to within two chips.
2. It does not require the stringent carrier recovery DSSS requires Conventional DSSS requires the carrier at the receiver to be phase locked to the received signal whereas MC-DSSS using the MC codes does not require phase locking the carriers. Commercially available crystals have sufficient stability for MC-DSSS.
3. It is spectrally efficient

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic showing for the Baseband Transmitter for the xth MC-DSSS frame: d(k)=[d(1,x) d(2,x) . . . d(N,k)] where c(i)=[c(1,i) c(2,i)] is the ith code and Sym (k)=[sym(1,k) sym(N,k)] is the kth information-bearing vector containing N symbols

FIG. 2 is a schematic showing a Baseband Receiver for the kth received MC-DSSS frame: d'(k)=[d'(1,k) d'(2,k) . d'(N,k)] where c(i)=[c(1,i) c(2,i) . . c(N,i)] is the ith code, Sym̂(k)=[sym̂(1,k) sym̂(2,k) . . sym̂(N,k)] is the estimate of the Kth information-bearing vector Sym(k) and



d'(k) ⊙ c(i) = c(1,i)d'(1 k) = c(2,i)d'(2,k) + . . + c(N,i)d'(N,N)

FIG. 3 is a schematic showing of the ith MC code c(i)=[c(i,1) c(i,2) . . . c(i,NO) where i can take one of the N values: 1,2, . . . N corresponding to the position of the single '1' at the input of the first N-point transform.

FIG. 4 is a schematic showing the alternate transmitter for the kth MC-DSSS frame: d(k)=[d(1,k), d(2,k) . . d(N,k)] using the MC codes generated in FIG. 3 where Sym(k)=[Sym(1,k)Sym(2k) . . Sym(N,k)] is the kth information-bearing vector contacting N symbols.

FIG. 5 is the alternate receiver for the kth received MC-DSSS frame d'(k)=[d'(1k)d'(2,K) . . d'(N,k)] using MC codes generated in FIG. 3 where Sym̂(k)=[sym̂(1,k) sym̂(2k) . . sym̂(N,k)] is the estimate of the information-bearing vetor Sym(k)

FIG. **6** is a schematic showing the Baseband Transmitter of the kth Data Frame X(k) where $Sym(N)=[sym(1,k)\ sym(2,k) \ldots sym(N,k)]$ is the kth information-bearing vector $d(k)=[c(1,k)\ d(2,k) \ldots d(N,k)]$ is the kth MC-DSSS frame $v(k)=[v(1,k)\ v(2,k) \ldots v((1+\beta)MN,k)]$, $\beta\epsilon(0,1)$, M=1,2,3 and $X(k)=[x(1k)\ x(2,k)]$, Z=Z=1, 2, 3,

FIG. **7** is a schematic showing the Baseband Receiver for the kth received Data Frame X'(k) where $Sy\hat{m}(N)=[sy\hat{m}(1,k)]\ sy\hat{m}(2,k) \ldots sy\hat{m}(N,k)]$ is the estimate of the kth information-bearing vector $d'(k)=[d'(1,k)\ d'(2k) \ldots d'(N,k)]$ is the kth received MC-DSSS frame $v'(k)=[v'(1,k)\ v(2k) \ldots v'((1+\beta)\ MN,k)]$, $B\epsilon(0,1)$, M=1,2,3, . . . and $X'(k)=[x'(1,k)\ x'(2,k) \ldots r'(Z,k)]$, Z=1,2,3

FIG. **8** is a schematic showing the Randomizer Transform (RT) where a (1) a (2) . . . a (N) are complex constants chosen randomly.

FIG. **9** is a schematic showing the Permutation Transform (PT).

FIG. **10** is a schematic showing (a) the shaping of a MC-DSSS frame and (b) the unshaping of a MC-DSSS frame where $d(k)=[d(1,k)\ d(2,k) \ldots d(N,k)]$ is the kth MC-DSSS frame $g(k)=[g(1,k)\ g(2k) \ldots g(MN,k)]$, M=1,2,3, . . . , $v(k)=[v(1,k)\ v(2,k) \ldots v((1+\beta)\ MN,k)]$, $B\epsilon(0,1)$ $d'(k)=[d(1,k)\ d(2,k) \ldots d(N,K)]$ is the kth received MC-DSSS frame $g'(k)=[g'(1,k)\ g'(2,k) \ldots g'(M'N,k)]$ and $v'(k)=[v(1,k)\ v'(2,k) \ldots v'((1+\beta)\ M'N,k)]$, M'=1,2,3,

FIG. **11** is a schematic showing (a) Description of the alias/window operation (b) Description of dealias/dewindow operation, where 1/T is the symbol rate.

FIG. **12** is a schematic showing the frame structure for data transmission from source (Node A) to destination (Node B).

FIG. **13** is a schematic showing the baseband transmitter for one request frame v where $c=[c(1)\ c(2) \ldots c(1)]$ is the DSSS code, $v=[v(1)\ v(2) \ldots v((1+\beta)MI)]$, $\beta\epsilon(0,1)$, M=1,2, . . . and I is the length of the DSSS code.

FIG. **14** is a schematic showing the baseband receiver for the received request frame where $c=[c(1)\ c(2) \ldots c(1)]$ is the DSSS code for the request frame, $d'=[d(1)\ d(2) \ldots d(1)]$ is the received request frame, $v'=[v'(1)\ v'((1+\beta)\ MI)]$, $\beta\epsilon(0,1)$, M=1,2, . . . and I is the length of the DSSS code

FIG. **15** is a schematic showing the baseband transmitter for one address frame where $c=[c(1)\ c(2) \ldots c(1)]$ is the CDMA code for the address frame, $v=[v(1)\ v(2) \ldots v(1+\beta)\ MI)]$, $\beta\epsilon(0,1)$, M=1,2, and I' is the length of the CDMA code.

FIG. **16** is a schematic showing the baseband receiver the address where $c=[c(1)\ c(2) \ldots c(I')]$ is the CDMA code for the address frame, $d'=[d(1)\ d(2) \ldots d(I)]$ is the received address frame, $v'[v'(1)\ v'(2) \ldots v'((1+\beta)\ MI')]$, $\beta\epsilon(0,1)$, M=1,2, . . . and I' is the length of the CDMA code

FIG. **17** is a schematic showing the baseband transmitter for Ack. Frame where $c=[c(1)\ c(2) \ldots c(I')]$ is the DSSS code for the Ack frame, $v=[v(1)\ v(2) \ldots v((I+\beta)\ MI')]$ $\beta\epsilon(0,1)$, M=1,2,3, . . . and I' is the length of the DSSS code.

FIG. **18** is a schematic showing the baseband receiver for the ack. frame where $c=[c(1)\ c(2) \ldots c(I'')]$ is the DSSS code for the Ack frame, $d'=[d(1)\ d(2) \ldots d'(I'')]$ is the received Ack frame, $v'=[v'(1)\ v(2) \ldots v'(1+\beta)\ MI'')]$, $\beta\epsilon(0,1)$, M=1,2, . . . and I'' is the length of the DSSS code.

FIG. **19** is a schematic showing the passband transmitter for a packet where f_o is the IF frequency and f_o+f_c is the RF frequency.

FIG. **20** is a schematic showing the passband receiver for a packet where f_o is the IF frequency and f_o+f_c is the RF frequency

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

FIG. 1 illustrates the transmitter of the MC-DSSS modulation technique generating the kth MC-DSSS frame bearing N symbols of information. The symbols can be either analog or digital

A converter **10** converts a stream of data symbols into plural sets of N data symbols each. A computing means **12** operates on the plural sets of N data symbols to produce modulated data symbols corresponding to an invertible randomized spreading of the stream of data symbols. A combiner **14** combines the modulated data symbols for transmission. The computing means shown in FIG. **1** includes a source **16** of N direct sequence spread spectrum code symbols and a modulator **18** to modulate each ith data symbol from each set of N data symbols with the I code symbol from the N code symbol to generate N modulated data symbols, and thereby spread each I data symbol over a separate code symbol

FIG. **2** illustrates the receiver of the MC-DSSS modulation techniques accepting the kth MC-DSSS frame and generating estimates for the corresponding N symbols of information. The dot product in FIG. **2** can be implemented as a correlator The detector can make either hard decisions or soft decisions.

A sequence of modulated data symbols is received at **22** in which the sequence of modulated data symbols has been generated by the transmitter such as is shown in FIG. **1** or **4**. A second computing means **24** operates on the sequence of modulated data symbols to produce an estimate of the second string of data symbols. The computing means **24** shown in FIG. **2** includes a correlator **26** for correlating each I modulated data symbol from the received sequence of modulated data symbols with the I code symbol from the set of N code symbols and a detector **28** for detecting an estimate of the data symbols from output of the correlator **26**.

FIG. **3** illustrates the code generator of the MC codes Any one of the P N-point transforms in FIG. **3** consists of a reversible transform to the extent of the available arithmetic precision. In other words, with finite precision arithmetic, the transforms are allowed to add a limited amount of irreversible error

One can use the MC-DSSS transmitter in FIG. **1** and the MC-DSSS receiver in FIG. **2** together with the MC codes generated using the code generator in FIG **3** in order to implement MC-DSSS using the MC codes.

An alternative transmitter to the one in FIG **1** using the MC codes in FIG **3** is shown in FIG **4**

The alternative transmitter shown in FIG. **4** includes a transformer **20** for operating on each set of N data symbols to generate N modulated data symbols as output A series of transforms are shown

An alternative receiver to the one in FIG. **2** using the MC codes in FIG **3** is shown in FIG **5** L pilots are required in FIG **5** for equalization

Both transmitters in FIGS **1** and **4** allow using shaper **30** in diversity module **32** shaping and time diversity of the MC-DSSS signal as shown in FIG **6**. We will refer to the MC-DSSS frame with shaping and time diversity as a Data frame.

Both receivers in FIGS. **2** and **5** allow diversity combining followed by the unshaping of the Data frame as shown in FIG. **7** A Synch is required in FIG **7** for frame synchronization.

In addition to the Data frames, we need to transmit (1) all of the L pilots used in FIG **5** to estimate and equalize for the various types of channel distortions, (2) the Synch signal used in FIG **7** for frame synchronization, and (3) depending on the access technique employed, the source address, destination address and number of Data frames We will refer to the combination of all transmitted frames as a packet

PREFERRED EMBODIMENTS OF THE INVENTION

Examples of the N-point transforms in FIG. **3** are a Discrete Fourier Transform (DFT), a Fast Fourier Transform

(FFT), a Walsh Transform (WT), a Hilbert Transform (HT), a Randomizer Transform (RT) as the one illustrated in FIG 8, a Permutator Transform (PT) as the one illustrated in FIG. 9, an Inverse DFT (IDFT), an Inverse FFT (IFFT), an Inverse WT (IWT), an Inverse HT (IHT), an Inverse RT (IRT), an Inverse PT (IPT), and any other reversible transform When L=2 with the first N-point transform being a DFT and the second being a RT, we have a system identical to the patent: "Method and Apparatus for Multiple Access between Transceivers in Wireless Communications using OFDM Spread Spectrum" by M Fattouche and H Zaghloul, filed in the U S Pat Office in Mar. 31, 1992, Ser. No. 07/861,725.

Preferred shaping in FIG 6 consists of an Mth order interpolation filter followed by an alias/window operation as shown in FIG 10a The Alias/window operation is described in FIG 11a where a raised-cosine pulse of rolloff β is applied The interpolation filter in FIG 10a can be implemented as an FIR filter or as an NM-point IDFT where the first N(M−1)/2 points and the last N(M−1)/2 points at the input of the IDFT are zero Preferred values of M are 1,2,3 and 4.

Preferred unshaping in FIG. 7 consists of a dealias/dewindow operation followed by a decimation filter as shown in FIG. 10b. The dealias/dewindow operation is described in FIG 11b.

Time Diversity in FIG. 6 can consist of repeating the MC-DSSS frame several times. It can also consist of repeating the frame several times then complex conjugating some of the replicas, or shifting some of the replicas in the frequency domain in a cyclic manner.

Diversity combining in FIG. 7 can consist of cophasing, selective combining, Maximal Ratio combining or equal gain combining.

In FIG 5, L pilots are used to equalize the effects of the channel on each information-bearing data frame. The pilot frames can consist of Data frames of known information symbols to be sent either before, during or after the data, or of a number of samples of known values inserted within two transformations in FIG 4 A preferred embodiment of the pilots is to have the first pilot consisting of a number of frames of known information symbols The remaining pilots can consist of a number of known information symbols between two transforms. The L estimators can consist of averaging of the pilots followed by either a parametric estimation or a nonparametric one similar to the channel estimator in the patent: "Method and Apparatus for Multiple Access between Transceivers in Wireless Communications using OFDM Spread Spectrum' by M. Fattouche and H Zaghloul, filed in the U S Pat Office in Mar. 31, 1992, Ser No. 07/861,725.

When Node A intends to transmit information to Node B, a preferred embodiment of a packet is illustrated in FIG. 12: a Request frame 40, an Address frame, an Ack frame, a Pilot frame 36 and a number of Data frames 38 The Request frame is used (1) as a wake-up call for all the receivers in the band, (2) for frame synchronization and (3) for packet synchronization. It can consist of a DSSS signal using one PN code repeated a number of times and ending with the same PN code with a negative polarity FIGS. 13 and 14 illustrate the transmitter and the receiver for the Request frame respectively. In FIG. 14, the dot product operation can be implemented as a correlator with either hard or soft decision (or equivalently as a filter matched to the PN code followed by a sample/hold circuit). The Request frame receiver is constantly generating a signal out of the correlator When the signal is above a certain threshold using the level detector, (1) a wake-up call signal is conveyed to the portion of the receiver responsible for the Address frame and (2) the frames are synchronized to the wake-up call The

packet is then synchronized to the negative differential correlation between the last two PN codes in the Request frame using a decoder as shown in FIG. 14

The Address frame can consist of a CDMA signal where one out of a number of codes is used at a time. The code consists of a number of chips that indicate the destination address, the source address and/or the number of Data frames FIGS. 15 and 16 illustrate the transmitter and the receiver for the Address frame respectively. Each receiver differentially detects the received Address frame, then correlates the outcome with it is own code. If the output of the correlator is above a certain threshold, the receiver instructs its transmitter to transmit an Ack Otherwise, the receiver returns to its initial (idle) state.

The Ack frame is a PN code reflecting the status of the receiver, i.e whether it is busy or idle. When it is busy, Node A aborts its transmission and retries some time later. When it is idle, Node A proceeds with transmitting the Pilot frame and the Data frames FIGS. 17 and 18 illustrate the transmitter and the receiver for the Address frame respectively.

An extension to the MC-DSSS modulation technique consists of passband modulation where the packet is up-converted from baseband to RF in the transmitter and later down-converted from RF to baseband in the receiver. Passband modulation can be implemented using IF sampling which consists of implementing quadrature modulation/demodulation in an intermediate Frequency between baseband and RF, digitally as shown in FIGS 19 and 20 which illustrate the transmitter and the receiver respectively. IF sampling trades complexity of the analog RF components (at either the transmitter, the receiver or both) with complexity of the digital components. Furthermore, in passband systems carrier feed-through is often a problem implying that the transmitter has to ensure a zero dc component. Such a component reduces the usable bandwidth of the channel. In IF sampling the usable band of the channel does not include dc and therefore is the dc component is not a concern.

A further extension to the MC-DSSS modulation technique consists of using antenna Diversity in order to improve the Signal-to-Ratio level at the receiver A preferred combining technique is maximal selection combining based on the level of the Request frame at the receiver.

We claim:

1. A transceiver for transmitting a first stream of data symbols, the transceiver comprising:

a converter for converting the first stream of data symbols into plural sets of N data symbols each;

first computing means for operating on the plural sets of N data symbols to produce modulated data symbols corresponding to an invertible randomized spreading of the first stream of data symbols; and

means to combine the modulated data symbols for transmission

2 The transceiver of claim 1 in which the first computing means [includes] *comprises*:

a source of [N] *more than one and up to M* direct sequence spread spectrum [code symbols] *codes, where M is the number of chips per direct sequence spread spectrum code*; and

a modulator to modulate each [ith] data symbol from each set of [N] data symbols with [the ith] *a* code [symbol] from the [N code symbol] *up to M direct sequence spread spectrum codes* to generate [N] modulated data symbols, and thereby spread each [ith data symbol] *set of data symbols* over a separate code [symbol].

3 The transceiver of claim 2 in which the [code symbols] *direct sequence spread spectrum codes* are generated by operation of a non-trivial [N point] transform on a sequence of input signals

4 The transceiver of claim **1** in which the first computing means [includes] *comprises*:

a transformer for operating on each set of N data symbols to generate [N] modulated data symbols as output, the [N] modulated data symbols corresponding to spreading of each [ith] data symbol over a separate code [symbol] *selected from a set of more than one and up to M codes, where M is the number of chips per code; and*

means to combine the modulated data symbols for transmission

5. The transceiver of claim **4** in which the transformer effectively applies a first transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform to the N data symbols

6 The transceiver of claim **5** in which the first transform is a Fourier transform and it is followed by a randomizing transform.

7 The transceiver of claim **6** in which the first transform is a Fourier transform and it is followed by a randomizing transform and a second transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform

8. The transceiver of claim **4** in which the transformer effectively applies a first inverse transform selected from the group [comprising] *consisting of* a randomizer transform, a Fourier transform and a Walsh transform to the N data symbols, followed by a first equalizer and a second inverse transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform.

9 The transceiver of claim **8** in which the second transform is followed by a second equalizer

10 The transceiver of claim **1** further [including] *comprising*:

means for receiving a sequence of modulated data symbols, the modulated data symbols having been generated by invertible randomized spreading of a second stream of data symbols; *and*

second computing means for operating on the sequence of modulated data symbols to produce an estimate of the second stream of data symbols

11 The transceiver of claim **10** further [including] *comprising* means to apply diversity to the modulated data symbols before transmission, and means to combine received diversity signals.

12 The transceiver of claim **10** in which the second computing means [includes] *comprises*:

a correlator for correlating each [ith] modulated data symbol from the received sequence of modulated data symbols with [the ith code symbol] *a code* from [the] *a* set of [N code symbols] *more than one and up to M codes, where M is the number of chips per code*; and

a detector for detecting an estimate of the data symbols from output of the correlator.

13 The transceiver of claim **10** in which the second computing means [includes] *comprises* an inverse transformer for regenerating an estimate of the [N] data symbols.

14 The transceiver of claim **1** further [including] *comprising* a shaper for shaping the combined modulated data symbols for transmission.

15. The transceiver of claim **1** further [including] *comprising* means to apply diversity to the combined modulated data symbols before transmission.

16. The transceiver of claim **1** in which the [N] data symbols include a pilot frame and a number of data frames, and is preceded by a request frame, wherein the request frame is used to wake up receiving transceivers, synchronize reception of the [N] data symbols and convey protocol information.

17. A transceiver for transmitting a first stream of data symbols and receiving a second stream of data symbols, the transceiver comprising:

a converter for converting the first stream of data symbols into plural sets of N data symbols each;

first computing means for operating on the plural sets of N data symbols to produce sets of [N] modulated data symbols corresponding to an invertible randomized spreading of each set of N data symbols over [N code symbols] *more than one and up to M direct sequence spread spectrum codes*;

means to combine the modulated data symbols for transmission;

means for receiving a sequence of modulated data symbols, the modulated data symbols having been generated by an invertible randomized spreading of a second stream of data symbols over [N code symbols] *more than one and up to M direct sequence spread spectrum codes*;

second computing means for operating on the sequence of modulated data symbols to produce an estimate of the second stream of data symbols; and

means to combine output from the second computing means.

18 The transceiver of claim **17** in which the first computing means [includes] *comprises*:

a source of [N] *the* direct sequence spread spectrum [code symbols] *codes*; and

a modulator to modulate each [ith] data symbol from each set of N data symbols with [the ith code symbol] *a code* from the [N code symbol] *up to M direct sequence spread spectrum codes* to generate [N] modulated data symbols, and thereby spread each [ith] data symbol over a separate *direct sequence spread spectrum* code [symbol]

19 The transceiver of claim **18** in which the [code symbols] *direct sequence spread spectrum codes* are generated by operation of plural non-trivial [N point] transforms on a random sequence of input signals.

20 The transceiver of claim **17** in which the first computing means [includes] *comprises*:

a transformer for operating on each set of N data symbols to generate [N] modulated data symbols as output, the [N] modulated data symbols corresponding to spreading of each [ith] data symbol over a separate code [symbol]

21 The transceiver of claim **17** in which the second computing means [includes] *comprises*:

a correlator for correlating each [ith] modulated data symbol from the received sequence of modulated data symbols with [the ith code symbol] *a code* from the [set of N code symbols] *up to M direct sequence spread spectrum codes*; and

a detector for detecting an estimate of the data symbols from the output of the correlator.

22 The transceiver of claim **17** in which the second computing means [includes] *comprises* an inverse transformer for regenerating an estimate of the N data symbols

23. A method of exchanging data streams between a plurality of transceivers, the method comprising the steps of:

converting a first stream of data symbols into plural sets of N data symbols each;

operating on the plural sets of N data symbols to produce modulated data symbols corresponding to a spreading of the first stream of data symbols over [N code symbols] *more than one and up to M direct sequence spread spectrum codes*;

combining the modulated data symbols for transmission; and

transmitting the modulated data symbols from a first transceiver at a time when no other of the plurality of transceivers is transmitting

24. The method of claim **23** in which the spreading is an invertible randomized spreading and operating on the plural sets of N data symbols [includes] *comprises* modulating each [ith] data symbol from each set of N data symbols with [the ith code symbol] *a code* from the [N code symbols] *up to M direct sequence spread spectrum codes* to generate [N] modulated data symbols, and thereby spread each [ith] data symbol over a separate code [symbol].

25. The method of claim **23** in which the spreading is an invertible randomized spreading and operating on the plural sets of N data symbols [includes] *comprises*:

transforming, by application of a transform, each set of N data symbols to generate [N] modulated data symbols as output.

26. The method of claim **25** in which transforming each set of N data symbols [includes] *comprises* applying to each set of N data symbols a randomizing transform and a transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform

27. The method of claim **25** in which transforming each set of N data symbols [includes] *comprises* applying to each set of N data symbols a Fourier transform, a randomizing transform and a transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform.

28. The method of claim **25** in which transforming each set of N data symbols [includes] *comprises* applying to each set of N data symbols a first transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform, a randomizing transform and a second transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform.

29 The method of claim **23** further [including] *comprising* the step of:

receiving, at a transceiver distinct from the first transceiver, the sequence of modulated data symbols; and

operating on the sequence of modulated data symbols to produce an estimate of the first stream of data symbols

30. The method of claim **29** in which operating on the sequence of modulated data symbols [includes] *comprises* the steps of:

correlating each [ith] modulated data symbol from the received sequence of modulated data symbols with [the ith code symbol from the set of N code symbols] *a code from the up to M direct sequence spread spectrum codes*; and

detecting an estimate of the first stream of data symbols from output of the correlator.

31. The method of claim **23** further [including] *comprising the step of* shaping the modulated data symbols before transmission.

32. The method of claim **23** further [including] *comprising the step of* applying diversity to the modulated data symbols before transmission.

33 A transceiver for transmitting a first stream of data symbols, the transceiver comprising:

a converter for converting the first stream of data symbols into plural sets of data symbols each;

first computing means for operating on the plural sets of data symbols to produce modulated data symbols corresponding to an invertible randomized spreading of the first stream of data symbols over more than one and up to M direct sequence spread spectrum codes, where each direct sequence spread spectrum code has M chips; and

means to combine the modulated data symbols for transmission.

34 The transceiver of claim 33 further comprising

means for receiving a sequence of modulated data symbols, the modulated data symbols having been generated by invertible randomized spreading of a second stream of data symbols; and

second computing means for operating on the sequence of modulated data symbols to produce an estimate of the second stream of data symbols

35 The transceiver of claim 34 further comprising means to apply diversity to the modulated data symbols before transmission, and means to combine received diversity signals.

36 The transceiver of claim 34 in which the second computing means comprises.

a correlator for correlating each modulated data symbol from the received sequence of modulated data symbols with a code from the set of up to M direct sequence spread spectrum codes; and

a detector for detecting an estimate of the data symbols from output of the correlator.

37 The transceiver of claim 34 in which the second computing means comprises an inverse transformer for regenerating an estimate of the data symbols

38 The transceiver of claim 33 further comprising a shaper for shaping the combined modulated data symbols for transmission.

39 The transceiver of claim 33 further comprising means to apply diversity to the combined modulated data symbols before transmission

40 The transceiver of claim 33 in which the data symbols include a pilot frame and a number of data frames, and is preceded by a request frame, wherein the request frame is used to wake up receiving transceivers, synchronize reception of the data symbols and convey protocol information

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : RE 37,802 E
DATED : July 23, 2002
INVENTOR(S) : M T. Fattouche et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [63], **Related U.S. Application Data**, insert in appropriate order

-- **Related U.S. Application Data**
[63] Continuation-in-part of U.S application
No. 07/861,725, filed on Mar 31, 1992, now Pat.
No. 5,282,222 --

Signed and Sealed this

Eleventh Day of March, 2003

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

Case 3:07-cv-06276-SI Document 31-4 Filed 01/31/2008 Page 8 of 19

EXHIBIT C

US005956323A

United States Patent [19]

Bowie

[11] Patent Number: 5,956,323

[45] Date of Patent: Sep. 21, 1999

[54] POWER CONSERVATION FOR POTS AND MODULATED DATA TRANSMISSION

[75] Inventor: Bruce H. Bowie, Santa Rose, Calif

[73] Assignee: Nokia High Speed Access Products Inc., Petaluma, Calif

[21] Appl. No.: 08/903,504

[22] Filed: Jul. 30, 1997

[51] Int. Cl.[6] H04M 11/00; H04Q 1/00

[52] U.S. Cl. 370/241; 379/413

[58] Field of Search 370/216, 241, 370/242, 244, 249, 250, 251, 204, 205, 212, 213; 379/1, 2, 5, 9, 15, 23, 26, 27, 32, 93 06, 399, 412, 413, 377

[56] References Cited

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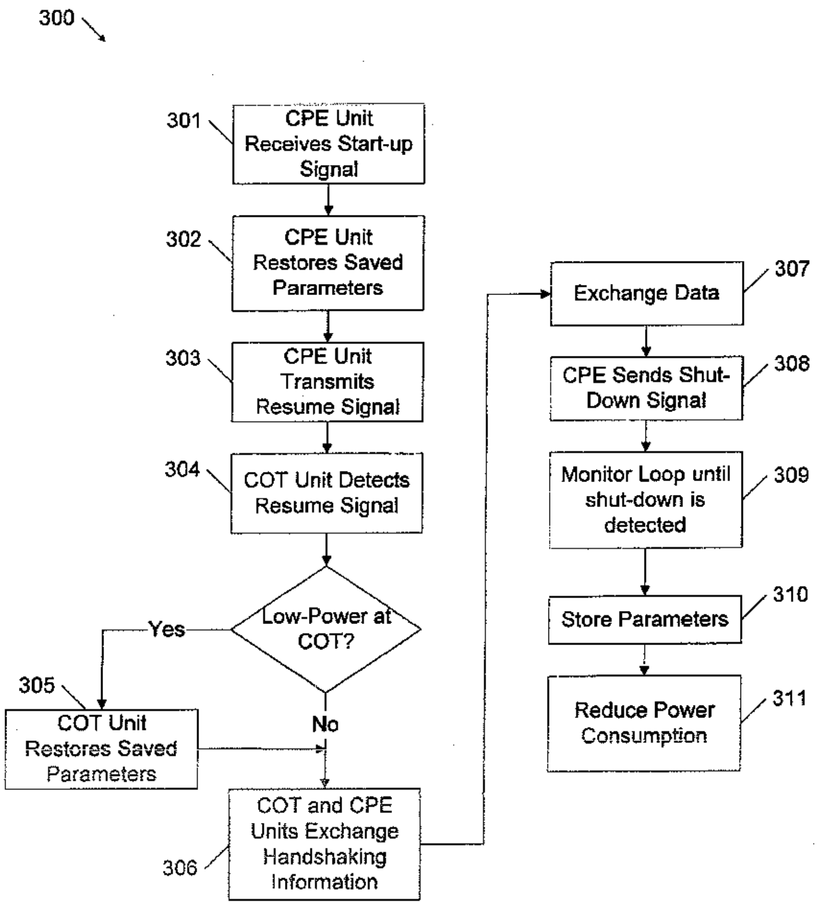
Primary Examiner—Chi H. Pham
Assistant Examiner—Kwang B. Yao
Attorney, Agent, or Firm—Fish & Richardson P.C.

[57] ABSTRACT

Methods and apparatus for conserving power in terminal units that transmit and receive modulated data over a communications loop that is shared with voiceband telephone equipment are disclosed. The methods include monitoring the loop to detect a shut-down condition and reducing power consumption of certain of the electronic circuits in the terminal unit upon detection of a shut-down condition. The methods also include monitoring the loop with a monitoring circuit to detect a resume signal outside the voiceband frequency range on the loop and restoring power to the electronic circuits when the resume signal is detected. The apparatuses include a modulated data transmitting and receiving unit having a connector for coupling the unit to a communications loop, circuitry to transmit and receive a modulated data signal in a frequency range above voiceband, and circuitry to detect a resume signal in the frequency range above voiceband and then to initiate a power up sequence for the transmit and receive circuitry.

27 Claims, 3 Drawing Sheets



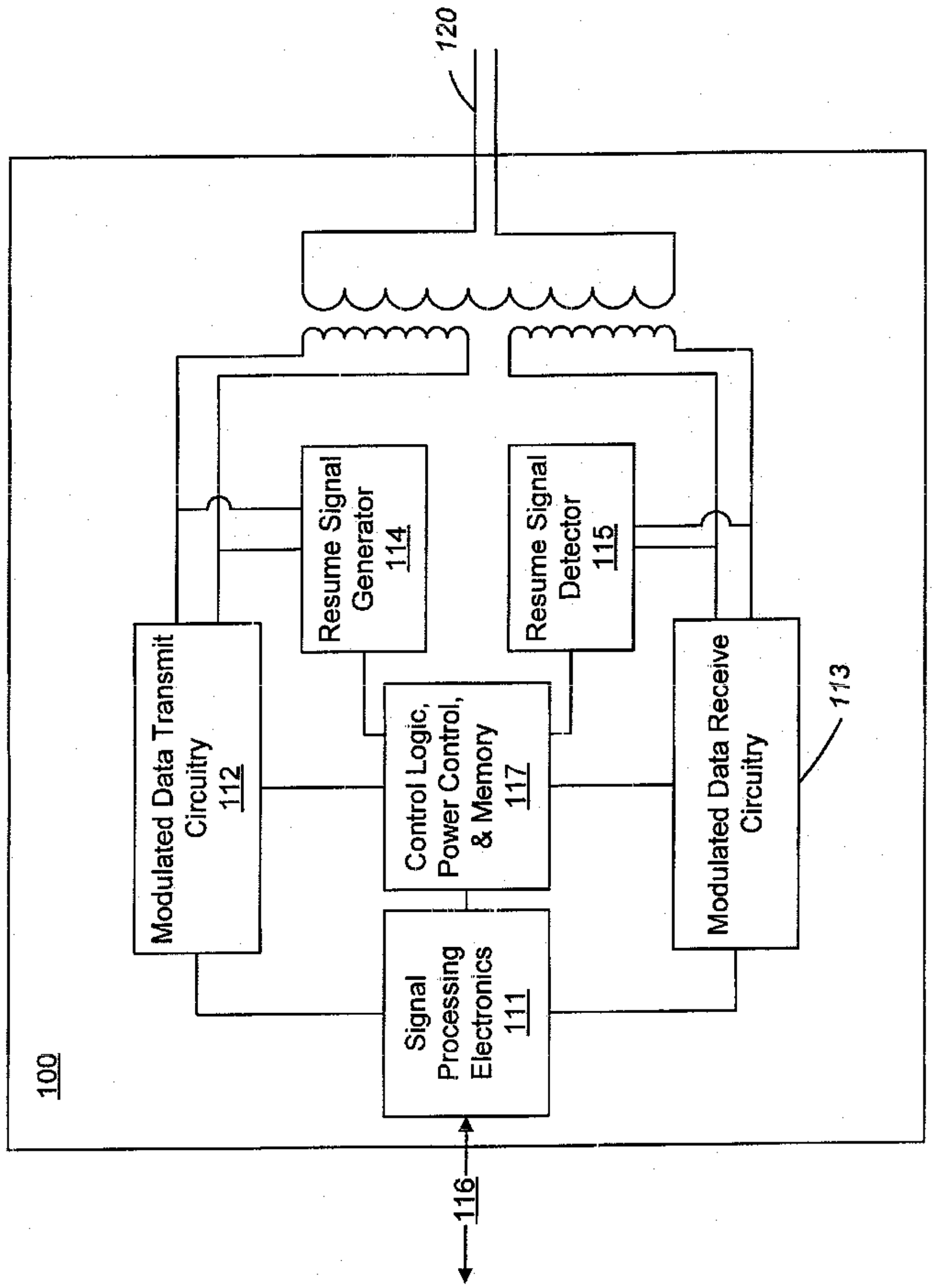

120
100
Resume Signal Generator 114
Resume Signal Detector 115
Modulated Data Transmit Circuitry 112
Control Logic, Power Control, & Memory 117
Modulated Data Receive Circuitry
113
Signal Processing Electronics 111
116

FIG. 1

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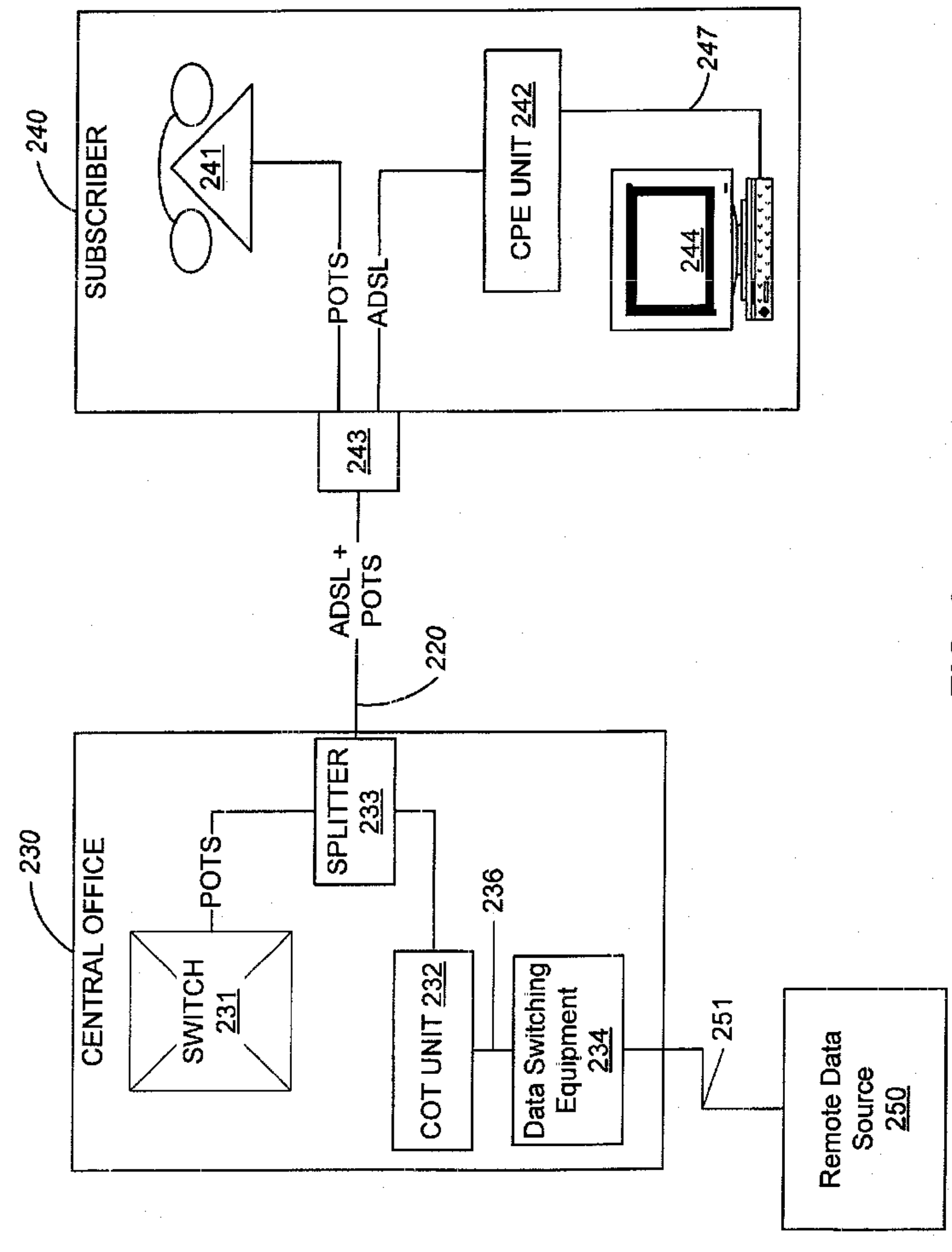

FIG. 2

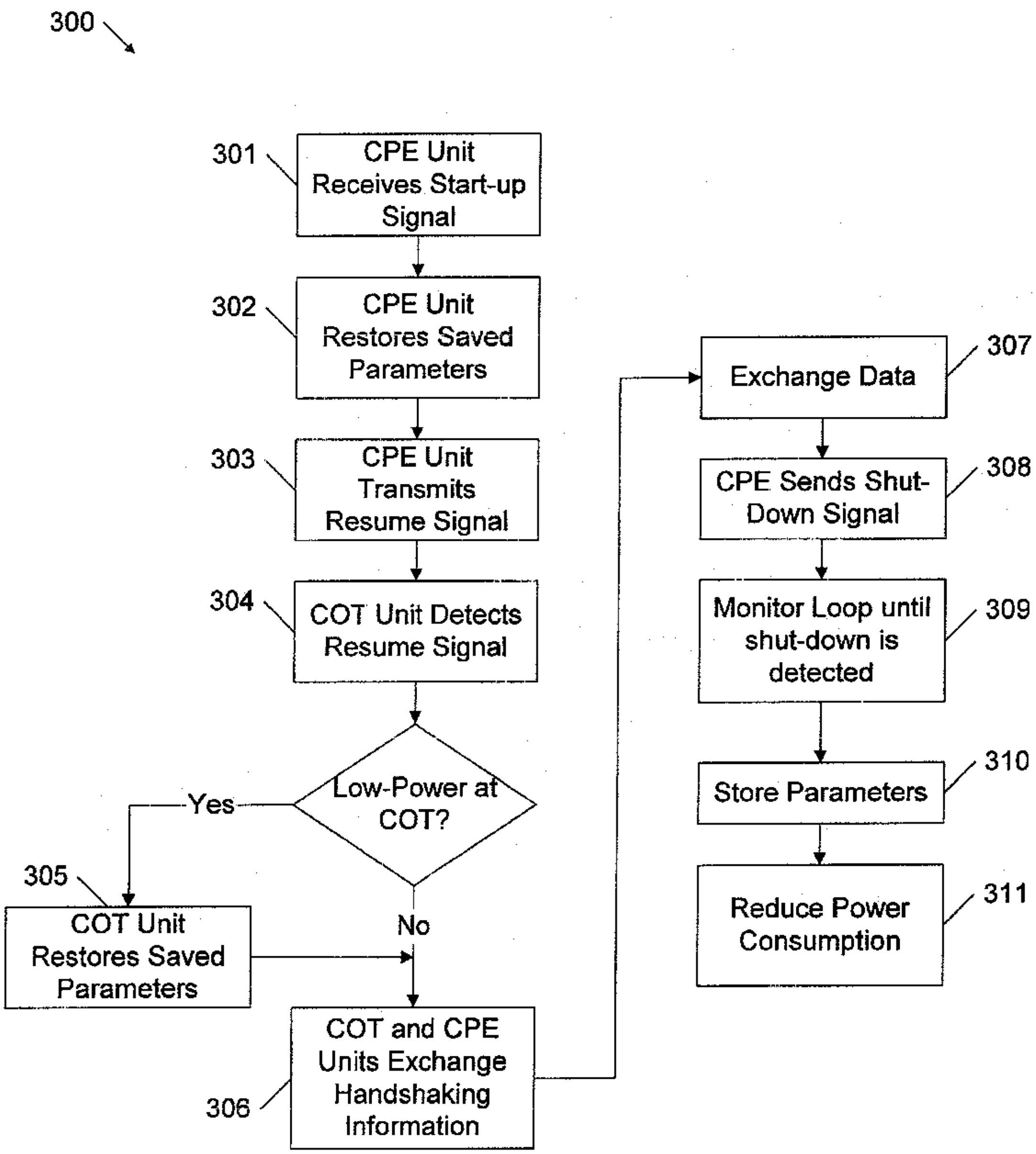
300
301
CPE Unit Receives Start-up Signal
302
CPE Unit Restores Saved Parameters
303
CPE Unit Transmits Resume Signal
304
COT Unit Detects Resume Signal
Low-Power at COT?
Yes
No
305
COT Unit Restores Saved Parameters
306
COT and CPE Units Exchange Handshaking Information
307
Exchange Data
308
CPE Sends Shut-Down Signal
309
Monitor Loop until shut-down is detected
310
Store Parameters
311
Reduce Power Consumption

FIG. 3

POWER CONSERVATION FOR POTS AND MODULATED DATA TRANSMISSION

The present invention is directed to a power conservation system for modulated data communications, and more particularly to a power conservation system for transmission systems in which data is modulated over a communications loop from a central office location to a customer premises

BACKGROUND

Wire loops extending from a telephone company central office to a customer premises are a ubiquitous part of the existing communications infrastructure These wire loops form a communications network often referred to as the plain old telephone service' (POTS) network The POTS network originated to support analog voice phone service

The POTS network currently supports a wide range of communications services in addition to analog voice phone calls. These services include digital data transmissions from facsimile (FAX) machines and computer modems Voice calls, FAX connections, and computer modem transmissions all operate within the frequency spectrum of traditional POTS calls, thus ensuring compatibility with the existing wire loop infrastructure and allowing transport of these services end-to-end through the POTS phone network However, the use of POTS-compatible transmission frequencies severely limits the maximum information carrying capacity of the wire loop

Certain transmission technologies may use carrier frequencies greater than those required for POTS services to exceed the information capacity limits of POTS calls over wire loops However, since the existing POTS loop infrastructure was not designed for carrying such high frequency signals, severe impediments to such transmission exist. In particular, as a result of electromagnetic coupling among wire loops, electromagnetic noise signals are induced on the loops. This electromagnetic coupling may occur among the large number of loops in the wire bundles that extend from the central office to various customer distribution points.

Noise signals induced on the loops by electromagnetic coupling may not be perceptible on POTS voice calls However, such signals may significantly interfere with wide-bandwidth modulated data transmissions that use high frequency signals To reduce interference problems, sophisticated signal processing circuitry, such as digital signal processors (DSPs), are used within modulated data receiver and transmitter units to remove noise, to encode and decode desired signals, and to perform error correction functions

To minimize the number of wire loops needed to service a customer's premises, POTS signals and modulated data transmission signals may be combined on a single wire loop. To combine POTS and wide-bandwidth modulated data transmission signals, the wide-bandwidth modulated data is transported using frequencies (spectrum) greater than those of POTS services. This spectrum usage allows a POTS service connection to be supported by its traditionally allocated spectrum while simultaneously supporting high frequency modulated data transmission. Thus, current technology permits POTS and high bandwidth data may be carried between customer premise equipment (CPE) and a central office (CO) on a single wire loop. At the central office, the POTS signal frequencies are separated from the high frequency data signal; the POTS signal is then handled by the existing POTS switch and network, while the high frequency spectrum is directed to separate processing components.

Signal processing, transmitting, and receiving circuitry for such high frequency modulated data signals requires a substantial amounts of power, typically up to 5 watts per loop served For a large central office, potentially serving many thousands of such data connections, this power usage is substantial

SUMMARY

In general, in one aspect, the invention features a method of conserving power in a terminal unit having a transmitter and receiver for modulated data communication over a communications loop that is shared with voiceband telephone equipment The method includes monitoring the loop to detect a shut-down condition, reducing power consumption of certain of the electronic circuits in the terminal unit upon detection of a shut-down condition, monitoring the loop with a monitoring circuit to detect a resume signal outside the voiceband frequency range on the loop, and restoring power to the electronic circuits when the resume signal is detected

Implementations of the invention may include one or more of the following features. The modulated data may be a bit stream including framing information, and a shut-down condition may be indicated by a loss of framing information The modulated data may include a signaling channel and a shut down condition may be indicated by bits transmitted in the signaling channel. The resume signal may be an AC signal at a frequency above voiceband, such as a 16 kHz AC signal.

In general, in another aspect, the invention features a modulated data transmitting and receiving unit. The unit includes a connector for coupling the unit to a communications loop, circuitry to transmit and receive a modulated data signal in a frequency range above voiceband, and circuitry to detect a resume signal in the frequency range above voiceband and then to initiate a power up sequence for the transmit and receive circuitry

Implementations of the invention may include one or more of the following features. The connector may be a two-wire connector The transmit and receive circuitry may include Asymmetric Digital Subscriber Line transmit and receive circuitry The resume signal detection circuitry may be a 16 kHz frequency detector. The communications loop may be a wireless communications loop The resume signal may be an AC signal greater than 4 kHz or may be a multi-tone AC signal. The unit may also include a control signal interface to receive a start-up signal, and circuitry to transmit a resume signal upon receipt of the start-up signal

In general, in another aspect, the invention features a modulated data transmitting and receiving unit The unit includes a connector for coupling the unit to a communications loop, a control signal interface for receiving a start-up signal, circuitry to transmit and receive a modulated data signal at frequencies above voiceband, and circuitry to transmit a resume signal on the loop upon receipt of a start-up signal on the control signal interface

Implementations of the invention may include one or more of the following features. The communications loop may a wireless loop. The control signal interface may be a data interface, such as a peripheral component interconnect (PCI) interface. The start-up signal may be indicated by receipt of data on the control signal interface. The control signal interface may be used for the exchange of both the start-up signal and of data between the modulated data transmitting and receiving unit and customer premise equipment.

Among the advantages of the invention are the following. Modulated data signal processing, transmitting, and receiving circuitry can be placed in a low power state when inactive, and then re-energized to resume full power operation as needed. Central office terminals (COTs) and customer premises equipment (CPE) units can exchange shutdown and resume signals without interfering with POTS services on the wire loop. Additionally, either a CPE or a COT unit can initiate both a low power state and resumption to a full power state.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an ADSL unit in accordance with the invention.

FIG. 2 is a diagram of a central office with a central office terminal (COT) ADSL unit connected by a two-wire loop to a customer premises equipment (CPE) ADSL unit in accordance with the invention.

FIG. 3 is a flowchart of a data exchange between two connected ADSL units in accordance with the invention.

DETAILED DESCRIPTION

Asymmetric Digital Subscriber Line (ADSL) technology is used to transmit wide-bandwidth modulated data over a two-wire loop using high frequency carrier signals. ADSL allows a two-wire loop to simultaneously transport POTS analog voice phone services along with high speed modulated digital data over wire loops of up to 18,000 feet. This simultaneous support of POTS and modulated digital services is provided by transporting POTS services using their traditionally allocated spectrum while transporting modulated digital data using spectrum outside of the POTS range.

FIG. 1 is a block diagram of an ADSL unit. To send and receive modulated digital data, the ADSL unit **100** employs high speed signal processing electronics **111** that includes, for example, digital signal processing (DSP) circuitry. Signal processing electronics **111** eliminate stray electronic noise induced on the two-wire loop **120** and, along with transmit circuitry **112** and receive circuitry **113**, are used to send and receive modulated data. In addition, signal processing circuitry **111** may implement error correcting algorithms, such as the Reed-Solomon algorithm, to further reduce data errors that arise during transmission. The signal processing, transmit, and receive functions may be provided by, for example, a Motorola CopperGold chip set or a GlobeSpan Technologies STAR or SLADE chip set. Control circuitry **117** is provided to control operation of the ADSL unit **100**, to control power usage by ADSL unit circuitry, and for storage of ADSL unit parameters.

To provision ADSL service, an ADSL unit **100** is located at each end of a wire loop **120**. Referring to FIG. 2, an ADSL unit **100** located at the subscriber premises **240** is referred to as a customer premises equipment (CPE) ADSL unit **242**. A second ADSL unit **100**, typically located at a telephone company central office **230**, is known as the central office terminal (COT) unit **232**. The CPE unit and the COT unit are connected by a two-wire loop **220** of up to 18,000 feet.

Central office and customer premises equipment connects to the ADSL unit through a data interface **116** (FIG. 1). At the central office end of the loop **230**, the data interface of the COT unit **232** is connected to central office data switching equipment **234**. At the subscriber end of the loop **240**, the data interface of the CPE unit **242** is connected to customer premise equipment such as a personal computer **244**.

Data to be transmitted by an ADSL unit is arranged in a structure known as a 'frame' prior to being transmitted. A frame is an arrangement of bits including both user data and signaling information required by the ADSL units. When there is nothing to transmit between ADSL units, the user data portion of the frame may be filled with idle packets. Within the ADSL framing structure is a low bit rate signaling channel over which handshaking information can be exchanged between ADSL units. This signaling channel may be used, for example, to test the wire loop transmission path and to send ADSL device status information.

Circuitry within each ADSL unit **232** and **242** is used to remove noise, to perform error correction, to multiplex data, and to transmit and receive data. This is done without interfering with POTS audio and signaling transmissions over the two-wire loop **220**, which uses spectrum below 4 kilohertz (kHz). Modulated data from the ADSL units **232** and **242** is transmitted using spectrum above 4 kHz, typically using a range of frequencies of 40 kHz and greater. Signal filters **233** and **243** (known as "splitters") are used to join signals being transmitted from one location, for example, the central office **230**, and to separate signals when they are received at the distant location, for example, the customer premises **240**.

Within the central office **230**, a splitter **233** is used to combine outgoing signals from the POTS switching equipment **231** and the COT ADSL unit **232** for transmission on the loop **220**. The splitter **233** also provides signals received on the two-wire loop **220** to both the POTS switching equipment **231** and to the COT ADSL unit **232**. Signals to be sent to the POTS switching equipment **231** are filtered by the splitter **233** so as to remove frequencies above voiceband. The resulting filtered signal may be handled by the POTS switch **231** as if it had originated on a traditional analog POTS connection. The signal from the splitter **233** to the COT ADSL unit **232** may contain the full frequency spectrum as it arrives over the wire loop **220** or may be filtered to remove voice band frequencies.

At the customer premises **240**, a splitter **243**, which may serve as a telephone company network interface (NI) device, is used to combine outgoing signals from customer premises POTS-compatible equipment **241** and the CPE ADSL unit **242** for transmission on the loop **220**. The splitter **243** is also used to direct signals received on the two-wire loop **220** to both customer premises POTS equipment **241**, such as an analog telephone or a FAX machine, and to the CPE ADSL unit **242**.

Signals to be sent to the customer premises POTS equipment **241** are filtered to remove frequencies above voice band. The resulting filtered signal may be handled by the customer premises POTS equipment **241** as if it had originated on a traditional analog POTS connection. The signal from the splitter **243** to the CPE ADSL unit **242** may contain the full frequency spectrum as it arrives over the wire loop **220** or it may be filtered to remove voiceband frequencies. The CPE ADSL unit **242** may be incorporated in, for example, an ADSL modem connected to a personal computer **244** that is programmed to send and receive over the ADSL connection. Circuitry to handle POTS and ADSL data functions may be combined within a single physical device handling signal splitting and filtering, POTS call processing and modulated data processing, transmitting, and receiving. Alternatively, these functions may be achieved using a number of physically separate devices.

Prior to initiating transport of modulated data over the loop **220**, signals are exchanged over the loop **220** between the COT unit **232** and the CPE unit **242** to adapt the ADSL units to the electronic characteristics of the particular wire

loop **220** For example, loop loss characteristics, which are a function of loop length, wire gauge, wire composition, and other factors, are exchanged This exchange of information is often referred to as handshaking Once handshaking is completed, transmission of user data may begin.

To reduce power requirements, the ADSL units **232** and **242** may enter low power mode when user data transmission is complete Either unit may initiate the low power mode. If, for example, the CPE unit **242** initiates low power mode, it does so by sending a shut-down signal to the COT unit **232**. This shut-down signal may be conveyed in the ADSL low bit rate signaling channel; alternatively, an out-of-band signal on the loop may be used, for example, a 16 kHz AC signal. Still another alternative is for the CPE unit to stop sending ADSL framing information (such as would happen if the CPE unit were powered down).

Upon receipt of the shut-down signal, the COT unit **232** optionally stores in memory **117** characteristics of the loop **220** that were determined by CPE to COT handshaking. Likewise, upon sending the shut-down signal, the CPE unit **242** may also optionally store the loop characteristics that it obtained through CPE to COT handshaking. Storing loop characteristics enables rapid resumption of user data transmission when the units are returned to full power mode. Each unit **232** and **242** may then enter low-power mode by shutting off the now unnecessary sections of signal processing **111**, transmitting **112**, and receiving **113** circuitry. The loop **220** will then be in an inactive state Circuitry **115** to detect the resume signal must remain capable of signal detection during low power operation If the COT unit **232** were to initiate low power mode, signals would be exchanged with the CPE unit **242** in a like fashion.

In alternative embodiments, both CPE **242** and COT **232** units may be capable of reduced power operation Alternatively, only the COT **232** unit may reduce its power consumption, or only the CPE unit **242** may reduce its power consumption If only the COT unit **232** is to reduce its power consumption, the COT unit **232** will not require resume signal generation **114** circuitry, nor will the CPE unit **242** require resume signal detection circuitry **115**. Similarly, if only the CPE unit **242** is to reduce power consumption, the CPE unit **242** will not require resume signal generation **114** circuitry nor will the COT unit **232** require resume signal detection circuitry. Thus, the particular circuit components that can be placed in a low power mode may vary among differing brands, models, and versions of ADSL units.

To return a unit that is in low power mode to full power operation, a resume signal is sent to the unit. In one embodiment, a COT ADSL unit resumes full power operation upon receipt of a 16 kHz AC signal that is sent over the wire loop by a CPE ADSL unit This resume signal may be detected by the COT unit using a 16 kHz AC signal detector **115** that employs conventional frequency detection techniques. This detector **115** remains operative when the unit **232** is in low-power mode. If the CPE unit **242** is capable of reduced power operation, a resume signal sent from the COT unit **232** to the CPE unit **242** would be similarly received at the customer premises and detected by the CPE unit **242**.

Upon receipt of the resume signal, the receiving ADSL unit returns the signal processing **111**, transmitting **112**, and receiving **113** circuitry to full power mode If loop transmission characteristics had been stored, these parameters are retrieved from memory **117** and used to enable data transmission to resume quickly by reducing the time needed to determine loop transmission characteristics. After resumption of full power mode, additional handshaking between

ADSL units **232** and **242** may occur Upon reaching a fully operational state, transmission of user data may resume.

Referring to FIGS. **2** and **3**, one exemplary application of the invention is to reduce power requirements needed to maintain a link between a personal computer (PC) **244** and a remote data source **250**. The remote data source **250** may be, for example, an Internet service provider (ISP) or an online service provider (OSP). In an exemplary configuration, a CPE ADSL unit **242** is connected by a digital interface **247** to a personal computer **244** programmed to send and receive data over the ADSL unit **242**. The CPE ADSL unit **242** may be incorporated in an ADSL modem that is installed in, or connected to, the PC **244**. The CPE ADSL unit **242** is connected by a wire loop **220** to a COT ADSL unit **232** at a central office **230** at which a link to the remote data source **250** exists.

In the exemplary configuration, the wire loop **220** is initially inactive, thus preventing information flow between the CPE **242** and COT **232** ADSL units To return the loop **220** to an active state, a start-up signal is sent to the CPE ADSL unit (step **301**) The start-up signal is, for example, a command sent over the digital interface **247** from a device driver or other program module running in the PC **244** or may be represented by power to the CPE ADSL unit being turned on. Upon receipt of the start-up signal, the CPE ADSL unit may restore saved loop characteristic parameters (step **302**). The CPE ADSL unit then transmits a 16 kHz resume signal on the loop (step **303**) The resume signal is subsequently detected by loop monitoring circuitry in the COT unit (step **304**). If the COT unit is in a low power state, it will return to full power operation upon detection of the resume signal from the CPE unit, this may include restoring loop characteristic parameters (step **305**). If the COT unit was not in a low power state, the resume signal may be ignored by the COT unit. CPE and COT ADSL units may then exchange handshaking information to establish reliable data communication between the units (step **306**) Handshaking information may be required where, for example, loop characteristics have changed due, for example, to temperature-dependent changes in loop resistance.

Handshaking information may also be exchanged for other device initialization purposes

Once reliable data transmission from the CPE to the COT ADSL units is established, information may be exchanged over the established data path (step **307**). Referring to FIG **2**, the personal computer **244** may use the data path between ADSL units to communicate with a remote data source by sending information over a digital interface **247** to the CPE ADSL unit **242**. This digital interface may be an industry standard computer interface such as a small computer systems interface (SCSI), an Ethernet interface, or a peripheral component interconnect (PCI) interface, or other industry standard or vendor proprietary interfaces allowing two-way data exchange. Information from the PC to the CPE unit may include both user data and signaling information to control CPE ADSL unit operation or, by relaying such signaling over an ADSL to ADSL unit signaling channel, to control COT ADSL unit operation. User data provided to the CPE unit by the PC is transmitted to the COT unit over the established CPE to COT data transmission path

Data received at the COT unit may be converted to a data signal format compatible with standard telephone company switching equipment, for example, a 1 544 million bits per second (Mbps) T1 data signal, or to asynchronous transfer mode (ATM) cells over an optical carrier level **3** (OC-3) synchronous optical network (SONET) interface. The

received data, now in a central office equipment compatible format, may be provided over a standard telephony interface **236** to telephone company high speed data switching equipment **234**, such as a digital cross connect switch or multiplexing equipment to a second interface **251** that connects to a remote data source **250**. Alternatively, the data may flow from the COT ADSL unit **232** directly to the remote data source **250** without handling by intermediary switching equipment **234**. Two way data transfers between the remote data source **250** and the PC **244** may then take place over the resulting path from PC **244** to CPE unit **242** to COT unit **232** to switching equipment **234** to remote data resource **250**.

Referring again to FIG. **3**, the COT unit may be returned to low power mode by sending a shut-down signal from the CPE unit to the COT unit (step **308**) The shut-down signal may be an expressly transmitted signal or may be inferred. For example, the shut down signal may be expressly sent as a series of signaling bits transmitted between the CPE and COT ADSL units. Alternatively, if the PC and COT ADSL unit are shut off, a shut-down signal may be inferred from the loss of transmitted framing information between the CPE unit and the COT unit. The shut-down signal is subsequently detected by monitoring circuitry in the COT ADSL unit (step **309**) Upon detecting a shut-down signal, the COT unit may save loop characteristics (step **310**) and enter low power mode by reducing power to now unnecessary circuitry (step **311**) The described procedure **300** may be repeated to resume data transmission Essentially the same sequence may occur to reduce power at a CPE ADSL unit **242**. A CPE ADSL unit may enter a low power mode when, for example, a preset or programmed period of time passes without any user activity on the data path or an appropriate signal is sent from the COT ADSL unit

Other embodiments are within the scope of the following claims. For example, while the invention has been described in the context of ADSL units providing an asymmetric data channel, the invention may be applied to other terminal units wherein voice band services share a loop with modulated data transmission, such as in Symmetric Digital Subscriber Line (SDSL) and Rate Adaptive Digital Subscriber Line (RADSL) terminal units Similarly, while systems with two-wire loops have been described, the invention may be used in systems including wireless loops and loop segments Wakeup signals may include multi tone signals and other signals outside the POTS spectrum. Terminal unit circuitry may include digital circuitry, analog circuitry, software, firmware, or a combination of these elements. The scope of the invention should be limited only as set forth in the claims that follow

What is claimed is:

1. A method of conserving power in a terminal unit having a transmitter and receiver for modulated data communication over a communications loop, comprising:

monitoring the loop to detect a shut-down condition;

reducing power consumption of demodulation circuitry in the terminal unit upon detection of a shut-down condition;

monitoring the loop with a monitoring circuit to detect a resume signal that is not a modulated data signal and that is outside the voiceband frequency range on the loop; and

activating demodulation circuitry when the resume signal is detected.

2. The method of claim **1** wherein modulated data comprises a bit stream including framing information, and a shut-down condition comprises a loss of framing information.

3. The method of claim **1** wherein modulated data comprises a bit frame including signaling bits and data bits and monitoring the loop to detect a shut-down condition comprises monitoring the signaling bits in the bit frame

4. The method of claim **1** where the resume signal comprises a 16 kHz AC signal.

5. The method of claim **1** further comprising:

storing loop characteristic parameters in a memory circuit upon detection of the shut-down condition; and

transferring loop characteristic parameters from the memory circuit to the demodulation circuitry upon activating the demodulation circuitry

6. The method of claim **5** further comprising performing handshaking to determine loop characteristics.

7. A modulated data transmitting and receiving unit, comprising:

a connector operatively coupling the unit to a communications loop;

first circuitry coupled to the connector to transmit and receive a modulated data signal in a frequency range above voiceband;

memory circuitry operatively coupled to the first circuitry to store loop characteristic parameters in a low-power state and to transfer loop characteristic parameters to the first circuitry during a power up sequence; and

second circuitry coupled to the connector to detect a resume signal in the frequency range above voiceband and then to initiate the power up sequence for the first circuitry.

8. The modulated data transmitting and receiving unit of claim **7** wherein the connector comprises a two-wire connector.

9. The modulated data transmitting and receiving unit of claim **7** wherein the first circuitry comprises asymmetric digital subscriber line data transmission circuitry.

10. The modulated data transmitting and receiving unit of claim **7** wherein the second circuitry comprises 16 kHz frequency detection circuitry.

11. The modulated data transmitting and receiving unit of claim **7** wherein the communications loop comprises a wireless communications loop

12. The modulated data transmitting and receiving unit of claim **7** wherein the resume signal comprises an AC signal greater than 4 kHz

13. The modulated data transmitting and receiving unit of claim **7** wherein the resume signal comprises transmission of an AC signal at a first frequency followed by transmission of an AC signal at a second frequency.

14. The modulated data transmitting and receiving unit of claim **6** further comprising:

a control signal interface for receiving a start-up signal; and

third circuitry coupled to the connector to transmit a resume signal on the loop upon receipt of a start-up signal on the control signal interface.

15. The apparatus of claim **7** wherein the first circuitry further comprises handshaking circuitry to determine loop characteristic parameters associated with the loop.

16. A modulated data transmitting and receiving unit, comprising:

a connector operatively coupling the unit to a communications loop;

a control signal interface for receiving a start-up signal;

first circuitry coupled to the connector to transmit and receive a modulated data signal at frequencies above voiceband;

memory circuitry operatively coupled to the first circuitry to store loop characteristic parameters in a low-power state and to transfer loop characteristic parameters to the first circuitry upon receipt of a start-up signal on a control signal interface; and

second circuitry coupled to the connector to transmit a resume signal on the loop upon receipt of the start-up signal on the control signal interface.

17. The modulated data transmitting and receiving unit of claim **16** wherein the communications loop comprises a two-wire communications loop.

18 The modulated data transmitting and receiving unit of claim **16** wherein the communications loop comprises a wireless communications loop

19. The modulated data transmitting and receiving unit of claim **16** wherein the control signal interface comprises a data interface.

20 The modulated data transmitting and receiving unit of claim **19** wherein the data interface comprises a peripheral component interconnect (PCI) interface

21. The modulated data transmitting and receiving unit of claim **19** wherein receipt of the start-up signal on the control signal interface comprises receipt of data on the control signal interface.

22. The modulated data transmitting and receiving unit of claim **16** wherein the control signal interface provides for exchange of a start-up signal and data between the modulated data transmitting and receiving unit and customer premise equipment

23 The apparatus of claim **16** wherein the first circuitry further comprises handshaking circuitry to determine loop characteristic parameters associated with the loop

24. A modulated data transmitting and receiving unit, comprising:

a connector operatively coupling the unit to a communications loop;

demodulator circuitry coupled to the connector to receive a modulated data signal on the loop;

power control circuitry coupled to the demodulator circuitry, the power control circuitry setting the demodulator circuitry in a reduced power state upon receipt of a low-power signal;

monitoring circuitry operatively coupled to the connector and to the power control circuitry, the monitoring circuitry being configured detect a shut-down condition on the loop and then to provide the low-power signal to the power control circuitry and

the monitor circuitry further comprises detector circuitry to detect a resume signal that is not a modulated data signal and that is outside the voiceband frequency range, and then to initiate a demodulator circuitry power up sequence.

25. The apparatus of claim **24** further comprising memory circuitry coupled to the demodulator circuitry to store loop characteristic parameters when the demodulator circuitry is in a reduced power state.

26. The apparatus of claim **25** wherein the demodulator circuitry, the power control circuitry, and the memory circuitry comprise a single integrated circuit

27. The apparatus of claim **24** wherein the detector circuitry comprises circuitry to detect an alternating current signal at a frequency above voiceband

* * * * *

JS 44 (Rev 11/04)

CIVIL COVER SHEET

2-07CV-474

RECEIVED-CLERK

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM.)

I. (a) PLAINTIFFS
Wi-LAN Inc.

EASTERN-MARSHALL

(b) County of Residence of First Listed Plaintiff: Ontario, Canada
(EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorney's (Firm Name, Address, and Telephone Number)
Sam Baxter, McKool Smith, P.C., 104 East Houston St., Suite 300
P.O. Box 0, Marshall, Texas 75670 (903) 923-9000

DEFENDANTS
See Attachment "A"

County of Residence of First Listed Defendant
(IN U.S. PLAINTIFF CASES ONLY)
NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE LAND INVOLVED.

Attorneys (If Known)

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

- ☐ 1 U.S. Government Plaintiff
- ☒ 3 Federal Question (U.S. Government Not a Party)
- ☐ 2 U.S. Government Defendant
- ☐ 4 Diversity (Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant) (For Diversity Cases Only)

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated *or* Principal Place of Business In This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated *and* Principal Place of Business In Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. NATURE OF SUIT (Place an "X" in One Box Only)

CONTRACT
- ☐ 110 Insurance
- ☐ 120 Marine
- ☐ 130 Miller Act
- ☐ 140 Negotiable Instrument
- ☐ 150 Recovery of Overpayment & Enforcement of Judgment
- ☐ 151 Medicare Act
- ☐ 152 Recovery of Defaulted Student Loans (Excl. Veterans)
- ☐ 153 Recovery of Overpayment of Veteran's Benefits
- ☐ 160 Stockholders' Suits
- ☐ 190 Other Contract
- ☐ 195 Contract Product Liability
- ☐ 196 Franchise

REAL PROPERTY
- ☐ 210 Land Condemnation
- ☐ 220 Foreclosure
- ☐ 230 Rent Lease & Ejectment
- ☐ 240 Torts to Land
- ☐ 245 Tort Product Liability
- ☐ 290 All Other Real Property

TORTS

PERSONAL INJURY
- ☐ 310 Airplane
- ☐ 315 Airplane Product Liability
- ☐ 320 Assault, Libel & Slander
- ☐ 330 Federal Employers' Liability
- ☐ 340 Marine
- ☐ 345 Marine Product Liability
- ☐ 350 Motor Vehicle
- ☐ 355 Motor Vehicle Product Liability
- ☐ 360 Other Personal Injury

PERSONAL INJURY
- ☐ 362 Personal Injury - Med. Malpractice
- ☐ 365 Personal Injury - Product Liability
- ☐ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
- ☐ 370 Other Fraud
- ☐ 371 Truth in Lending
- ☐ 380 Other Personal Property Damage
- ☐ 385 Property Damage Product Liability

CIVIL RIGHTS
- ☐ 441 Voting
- ☐ 442 Employment
- ☐ 443 Housing/ Accommodations
- ☐ 444 Welfare
- ☐ 445 Amer. w/Disabilities - Employment
- ☐ 446 Amer. w/Disabilities - Other
- ☐ 440 Other Civil Rights

PRISONER PETITIONS
- ☐ 510 Motions to Vacate Sentence

Habeas Corpus:
- ☐ 530 General
- ☐ 535 Death Penalty
- ☐ 540 Mandamus & Other
- ☐ 550 Civil Rights
- ☐ 555 Prison Condition

FORFEITURE/PENALTY
- ☐ 610 Agriculture
- ☐ 620 Other Food & Drug
- ☐ 625 Drug Related Seizure of Property 21 USC 881
- ☐ 630 Liquor Laws
- ☐ 640 R.R. & Truck
- ☐ 650 Airline Regs.
- ☐ 660 Occupational Safety/Health
- ☐ 690 Other

LABOR
- ☐ 710 Fair Labor Standards Act
- ☐ 720 Labor/Mgmt. Relations
- ☐ 730 Labor/Mgmt. Reporting & Disclosure Act
- ☐ 740 Railway Labor Act
- ☐ 790 Other Labor Litigation
- ☐ 791 Empl. Ret. Inc. Security Act

BANKRUPTCY
- ☐ 422 Appeal 28 USC 158
- ☐ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
- ☐ 820 Copyrights
- ☒ 830 Patent
- ☐ 840 Trademark

SOCIAL SECURITY
- ☐ 861 HIA (1395ff)
- ☐ 862 Black Lung (923)
- ☐ 863 DIWC/DIWW (405(g))
- ☐ 864 SSID Title XVI
- ☐ 865 RSI (405(g))

FEDERAL TAX SUITS
- ☐ 870 Taxes (U.S. Plaintiff or Defendant)
- ☐ 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
- ☐ 400 State Reapportionment
- ☐ 410 Antitrust
- ☐ 430 Banks and Banking
- ☐ 450 Commerce
- ☐ 460 Deportation
- ☐ 470 Racketeer Influenced and Corrupt Organizations
- ☐ 480 Consumer Credit
- ☐ 490 Cable/Sat TV
- ☐ 810 Selective Service
- ☐ 850 Securities/Commodities/ Exchange
- ☐ 875 Customer Challenge 12 USC 3410
- ☐ 890 Other Statutory Actions
- ☐ 891 Agricultural Acts
- ☐ 892 Economic Stabilization Act
- ☐ 893 Environmental Matters
- ☐ 894 Energy Allocation Act
- ☐ 895 Freedom of Information Act
- ☐ 900 Appeal of Fee Determination Under Equal Access to Justice
- ☐ 950 Constitutionality of State Statutes

V. ORIGIN (Place an "X" in One Box Only)

☒ 1 Original Proceeding ☐ 2 Removed from State Court ☐ 3 Remanded from Appellate Court ☐ 4 Reinstated or Reopened ☐ 5 Transferred from another district (specify) ☐ 6 Multidistrict Litigation ☐ 7 Appeal to District Judge from Magistrate Judgment

VI. CAUSE OF ACTION

Cite the U.S. Civil Statute under which you are filing (**Do not cite jurisdictional statutes unless diversity**):

Brief description of cause: 35 USC 271; Infringement of Patent

VII. REQUESTED IN COMPLAINT: ☐ CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23 **DEMAND $**

CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ Yes ☐ No

VIII. RELATED CASE(S) IF ANY (See instructions): JUDGE DOCKET NUMBER

DATE 10/31/07 SIGNATURE OF ATTORNEY OF RECORD Sam Baxter

FOR OFFICE USE ONLY

RECEIPT # AMOUNT APPLYING IFP JUDGE MAG. JUDGE

ATTACHMENT "A"

1. Westell Technologies, Inc.
2. NETGEAR, Inc.
3. 2Wire, Inc.
4. D-Link Systems, Inc.
5. D-Link Corporation
6. Belkin International, Inc.
7. Buffalo Technology (USA), Inc.
8. Melco Holdings Inc.
9. Broadcom Corporation
10. Atheros Communications, Inc.
11. Marvell Semiconductor, Inc.
12. Texas Instruments, Incorporated
13. Infineon Technologies North America Corporation
14. Infineon Technologies AG
15. Intel Corporation
16. Best Buy Co., Inc.
17. Circuit City Stores, Inc.

UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

WI-LAN INC., Plaintiff, v. ACER, INC., ACER AMERICA CORPORATION, APPLE, INC., DELL, INC., GATEWAY, INC., HEWLETT-PACKARD COMPANY, LENOVO GROUP LTD., LENOVO (UNITED STATES) INC., SONY CORPORATION, SONY CORPORATION OF AMERICA, SONY ELECTRONICS, INC., SONY COMPUTER ENTERTAINMENT AMERICA, INC., TOSHIBA CORPORATION, TOSHIBA AMERICA, INC., TOSHIBA AMERICA INFORMATION SYSTEMS, INC., BROADCOM CORPORATION, INTEL CORPORATION, ATHEROS COMMUNICATIONS, INC, MARVELL SEMICONDUCTOR, INC., BEST BUY CO., INC., and CIRCUIT CITY STORES, INC. Defendants.	§ §	Civil Action No. 2-07CV-473 TJW JURY TRIAL REQUESTED

ORIGINAL COMPLAINT

Plaintiff Wi-LAN Inc ("Wi-LAN") files this Original Complaint for patent infringement against Defendants Acer, Inc., Acer America Corporation ("Acer"), Apple, Inc ("Apple"), Dell, Inc ("Dell"), Gateway, Inc ("Gateway"), Hewlett-Packard Company ("Hewlett-Packard"), Lenovo Group Ltd., Lenovo (United States) Inc ("Lenovo"), Sony Corporation, Sony Corporation of America, Sony Electronics, Inc., Sony Computer Entertainment America, Inc. ("Sony"), Toshiba Corporation, Toshiba America, Inc., Toshiba America Information Systems, Inc. ("Toshiba") (collectively

"Defendant Suppliers"), Broadcom Corporation ("Broadcom"), Intel Corporation ("Intel"), Atheros Communications, Inc. ("Atheros"), Marvell Semiconductor, Inc ("Marvell"), Best Buy Co., Inc. ("Best Buy"), and Circuit City Stores, Inc. ("Circuit City"), for infringement of U.S. Patent No. 5,282,222 (the "'222 Patent") and U.S. Patent No. RE37,802 (the "'802 Patent") (collectively, the "Patents-in-Suit") pursuant to 35 U.S.C. § 271. Copies of the Patents-in-Suit are attached as Exhibits A and B.

PARTIES

1. Plaintiff Wi-LAN Inc is a corporation existing under the laws of Canada with its principal place of business at 11 Holland Ave., Suite 608, Ottawa, Ontario, Canada.

2. Upon information and belief, Defendant Acer, Inc., is a Taiwanese Corporation with its principal place of business at 8F, 88, Sec 1, Hsin Tai Wu Rd., Hsichih 221, Taiwan. Upon information and belief, Defendant Acer America Corporation is a California Corporation with its principal place of business at 2641 Orchard Pkwy., San Jose, CA 95134 Acer manufactures for sale and/or sells personal computers and/or other Acer-branded products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Upon information and belief, Defendants Acer, Inc. and Acer America Corporation are commonly owned by the same corporate entity and are alter egos and/or agents of one another. Acer may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

3. Upon information and belief, Defendant Apple is a California Corporation with its principal place of business at 1 Infinite Loop, Cupertino, CA 95014. Apple

manufactures for sale and/or sells personal computers and/or other Apple-branded products with wireless capability compliant with the IEEE 802 11 standards in the United States and, more particularly, in the Eastern District of Texas. Apple may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

4. Upon information and belief, Defendant Dell is a Delaware Corporation with its principal place of business at 1 Dell Way, Round Rock, TX 78682-2222. Dell manufactures for sale and/or sells personal computers and/or other Dell-branded products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Dell may be served with process by serving its registered agent, Corporation Service Company at 701 Brazos Street, Suite 1050, Austin, Texas 78701.

5. Upon information and belief, Defendant Gateway is a Delaware Corporation with its principal place of business at 7565 Irvine Center Dr., Irvine, CA 92618. Gateway manufactures for sale and/or sells personal computers and/or other Gateway-branded products with wireless capability compliant with the IEEE 802 11 standards in the United States and, more particularly, in the Eastern District of Texas Gateway may be served with process by serving its registered agent, CT Corporation System at 818 West Seventh Street, Los Angeles, California 90017.

6. Upon information and belief, Defendant Hewlett-Packard is a Delaware Corporation with its principal place of business at 300 Hanover St., Palo Alto, CA 94304. Hewlett-Packard manufactures for sale and/or sells personal computers and/or other Hewlett-Packard-branded products with wireless capability compliant with the

IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Hewlett-Packard may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

7. Upon information and belief, Defendant Lenovo Group Ltd. is a Hong Kong Corporation with its principal place of business at 1009 Think Place, Bldg. 500, Box 29, Morrisville, NC 27560. Upon information and belief, Defendant Lenovo (United States) Inc. is a Delaware Corporation with its principal place of business at 1009 Think Place, Bldg. 500, Box 29, Morrisville, NC 27560. Lenovo manufactures for sale and/or sells personal computers and/or other Lenovo-branded products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Upon information and belief, Defendants Lenovo Group Ltd. and Lenovo (United States) Inc. of North America are commonly owned by the same corporate entity and are alter egos and/or agents of one another. Lenovo may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

8. Upon information and belief, Defendant Sony Corporation is a Japanese Corporation with its principal place of business at 7-35 Kitashinagawa 6-Chome Shinagawa-KU, Tokyo 141 Japan. Upon information and belief, Defendant Sony Corporation of America is a New York Corporation with its principal place of business at 555 Madison Ave. 8th Floor, New York, NY 10022. Upon information and belief, Defendant Sony Electronics, Inc. is a Delaware Corporation with its principal place of business at 16450 W. Bernardo Dr., San Diego, CA 92127. Upon information and belief, Defendant Sony Computer Entertainment America, Inc. is a Delaware Corporation with

its principal place of business at 919 E Hillsdale Blvd , Foster City, CA 94404 Sony manufactures for sale and/or sells personal computers and/or other Sony-branded products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Upon information and belief, Defendants Sony Corporation, Sony Corporation of America, Sony Electronics, Inc., and Sony Computer Entertainment America, Inc. are commonly owned by the same corporate entity and are alter egos and/or agents of one another. Sony may be served with process by serving its registered agent, Corporation Service Company at 701 Brazos Street, Suite 1050, Austin, Texas 78701.

9. Upon information and belief, Defendant Toshiba Corporation is a Japanese Corporation with its principal place of business at 1-1, Shibaura 1-chrome, Minato-ku, Tokyo 105-8001, Japan. Upon information and belief, Defendant Toshiba America, Inc. is a Delaware Corporation with its principal place of business at 1251 Avenue of the Americas Suite 4110, New York, NY 10020 Upon information and belief, Defendant Toshiba America Information Systems, Inc. is a California Corporation with its principal place of business at 9740 Irvine Blvd., Irvine, CA 92618. Toshiba manufactures for sale and/or sells personal computers and/or other Toshiba-branded products with wireless capability compliant with the IEEE 802 11 standards in the United States and, more particularly, in the Eastern District of Texas. Upon information and belief, Defendants Toshiba Corporation, Toshiba America, Inc. and Toshiba America Information Systems, Inc. are commonly owned by the same corporate entity and are alter egos and/or agents of one another. Toshiba may be served with process by serving

its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

10. Upon information and belief, Defendant Broadcom is a California Corporation with its principal place of business at 5300 California Ave., Irvine, CA 92617. Broadcom manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Broadcom may be served with process by serving its registered agent, National Registered Agents, Inc. at 2030 Main Street, Suite 1030, Irvine, California 92614.

11. Upon information and belief, Defendant Intel is a Delaware Corporation with its principal place of business at 2200 Mission College Blvd., Santa Clara, CA 95054-1549. Intel manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Intel may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

12. Upon information and belief, Defendant Atheros is a Delaware Corporation with its principal place of business at 5480 Great America Pkwy., Santa Clara, CA 95054. Atheros manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant

with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Atheros may be served with process by serving its registered agent, LexisNexis Document Solutions, Inc. at 701 Brazos Street, Suite 1050, Austin, Texas 78701

13. Upon information and belief, Defendant Marvell Semiconductor, Inc. is a California Corporation with its principal place of business at 5488 Marvell Ln., Santa Clara, CA 95054-3606. Marvell manufactures for sale and/or sells integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Marvell may be served with process by serving its registered agent, CT Corporation System, at 818 West Seventh Street, Los Angeles, California 90017

14. Upon information and belief, Defendant Best Buy is a Minnesota Corporation with its principal place of business at 7601 Penn Ave. S., Richfield, MN 55423. Best Buy offers for sale and/or sells one or more of the Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards in the United States and, more particularly, in the Eastern District of Texas. Best Buy may be served with process by serving its registered agent, CT Corporation System at 350 N. St. Paul Street, Dallas, Texas 75201.

15. Upon information and belief, Defendant Circuit City is a Virginia Corporation with its principal place of business at 9950 Mayland Dr., Richmond, VA

23233 Circuit City offers for sale and/or sells one or more of the Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802 11 standards in the United States and, more particularly, in the Eastern District of Texas. Circuit City may be served with process by serving its registered agent, Prentice Hall Corporation System, Inc. at 701 Brazos Street, Suite 1050, Austin, Texas 78701.

JURISDICTION AND VENUE

16 This is an action for patent infringement under the Patent Laws of the United States, 35 U.S.C. § 271.

17. This Court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1331 and 1338(a)

18. This Court has personal jurisdiction over each Defendant. Each Defendant has conducted and does conduct business within the State of Texas. Each Defendant, directly or through intermediaries (including distributors, retailers, and others), imports, ships, distributes, offers for sale, sells, and advertises (including the provision of an interactive web page) its products in the United States, the State of Texas, and the Eastern District of Texas. Each Defendant has purposefully and voluntarily placed one or more of its infringing products, as described below, into the stream of commerce with the expectation that they will be purchased by consumers in the Eastern District of Texas. These infringing products have been and continue to be purchased by consumers in the Eastern District of Texas. Each Defendant has committed the tort of patent infringement within the State of Texas, and particularly, within the Eastern District of Texas.

19. Venue is proper in this Court pursuant to 28 U.S.C. §§ 1391 and 1400(b)

COUNT I: PATENT INFRINGEMENT

20. On January 25, 1994, the United States Patent and Trademark Office ("USPTO") duly and legally issued the '222 Patent, entitled "Method and Apparatus for Multiple Access Between Transceivers in Wireless Communications Using OFDM Spread Spectrum" after a full and fair examination. Wi-LAN is the assignee of all rights, title, and interest in and to the '222 Patent and possesses all rights of recovery under the '222 Patent, including the right to recover damages for past infringement.

21. On July 23, 2002, the USPTO duly and legally issued the '802 Patent, entitled "Multicode Direct Sequence Spread Spectrum" after a full and fair examination. Wi-LAN is the assignee of all rights, title, and interest in and to the '802 Patent and possesses all rights of recovery under the '802 Patent, including the right to recover damages for past infringement.

22. Each of the Patents-in-Suit is valid and enforceable.

23. Upon information and belief, Acer has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Acer-branded products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

24. Upon information and belief, Apple has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally

and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Apple-branded products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

25. Upon information and belief, Dell has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Dell-branded products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

26 Upon information and belief, Gateway has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Gateway-branded products with wireless capability compliant with the IEEE 802 11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

27. Upon information and belief, Hewlett-Packard has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Hewlett-Packard-branded products with wireless

capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

28. Upon information and belief, Lenovo has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Lenovo-branded products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

29. Upon information and belief, Sony has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Sony-branded products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

30. Upon information and belief, Toshiba has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling personal computers and/or other Toshiba-branded products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

31. Upon information and belief, Broadcom has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere

by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

32. Upon information and belief, Intel has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

33. Upon information and belief, Atheros has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

34. Upon information and belief, Marvell has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally

and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling integrated circuits and/or circuit boards used and/or designed for use in Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

35. Upon information and belief, Best Buy has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling one or more of the Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit.

36. Upon information and belief, Circuit City has been and is now infringing, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit in this District and elsewhere by making, using, offering for sale, importing, and/or selling one or more of the Defendant Suppliers' personal computers and/or Defendant Suppliers' other accused products with wireless capability compliant with the IEEE 802.11 standards that fall within the scope of at least one claim of each of the Patents-in-Suit

37. Wi-LAN has no adequate remedy at law against Defendants' acts of infringement and, unless Defendants are enjoined from their infringement of the Patents-in-Suit, Wi-LAN will suffer irreparable harm.

38 Many of the Defendants have had knowledge of the Patents-in-Suit and have not ceased their infringing activities These Defendants' infringement of the Patents-in-Suit has been and continues to be willful and deliberate. All the Defendants have knowledge of the Patents-in-Suit by way of this complaint and to the extent they do not cease their infringing activities their infringement is and continues to be willful and deliberate.

39. Wi-LAN is in compliance with the requirements of 35 U S.C. § 287.

40 Defendants, by way of their infringing activities, have caused and continue to cause Wi-LAN to suffer damages in an amount to be determined at trial.

PRAYER FOR RELIEF

WHEREFORE, Wi-LAN prays for the following relief:

A. A judgment in favor of Wi-LAN that Defendants have infringed, directly and indirectly by way of inducement and/or contributory infringement, literally and/or under the doctrine of equivalents, the Patents-in-Suit;

B A permanent injunction, enjoining Defendants and their officers, directors, agents, servants, employees, affiliates, divisions, branches, subsidiaries, parents and all others acting in concert or privity with any of them from infringing, inducing the infringement of, or contributing to the infringement of the Patents-in-Suit;

C. Award to Wi-LAN the damages to which it is entitled under 35 U S.C. § 284 for Defendants' past infringement and any continuing or future infringement up until the date Defendants are finally and permanently enjoined from further infringement, including both compensatory damages and treble damages for willful infringement;

E. A judgment and order requiring Defendants to pay the costs of this action (including all disbursements), as well as attorneys' fees as provided by 35 U.S.C. § 285;

F. Award to Wi-LAN pre-judgment and post-judgment interest on its damages; and

G. Such other and further relief in law or in equity to which Wi-LAN may be justly entitled.

DEMAND FOR JURY TRIAL

Wi-LAN demands a trial by jury of any and all issues triable of right before a jury.

DATED: October 31, 2007

Respectfully submitted,

McKool Smith, P.C.

Sam Baxter

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Lead Attorney
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ATTORNEYS FOR WI-LAN INC.

Austin 39878v9

EXHIBIT A

US005282222A

United States Patent [19]

Fattouche et al.

[11] **Patent Number: 5,282,222**

[45] **Date of Patent: Jan. 25, 1994**

[54] **METHOD AND APPARATUS FOR MULTIPLE ACCESS BETWEEN TRANSCEIVERS IN WIRELESS COMMUNICATIONS USING OFDM SPREAD SPECTRUM**

[76] Inventors: **Michel Fattouche**, 156 Hawkwood Blvd. N.W., Calgary, Alberta, Canada, T3G 2T2; **Hatim Zaghloul**, 402 - 1st Avenue, N.E., Calgary, Alberta, Canada, T2E 0B4

[21] Appl. No.: **861,725**

[22] Filed: **Mar. 31, 1992**

[51] **Int. Cl.**[5] **H04K 1/00**
[52] **U.S. Cl.** **375/1; 380/34**
[58] **Field of Search** 380/34; 375/1; 364/724.01, 827

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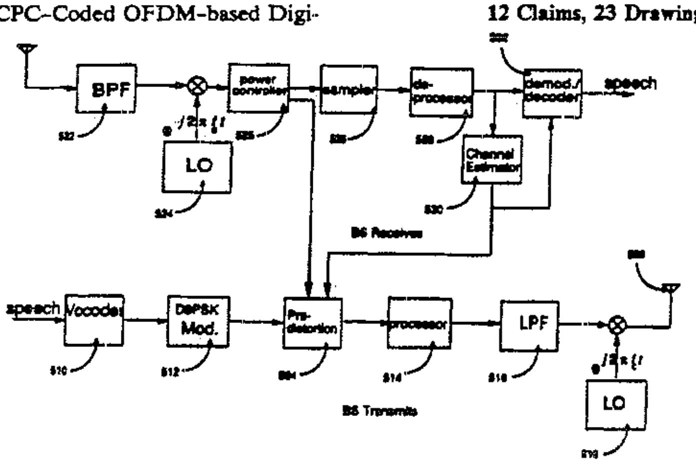
(List continued on next page.)

Primary Examiner—Tod R. Swann
Attorney, Agent, or Firm—Daniel L. Dawes

[57] **ABSTRACT**

A method for allowing a number of wireless transceivers to exchange information (data, voice or video) with each other. A first frame of information is multiplexed over a number of wideband frequency bands at a first transceiver, and the information transmitted to a second transceiver. The information is received and processed at the second transceiver. The information is differentially encoded using phase shift keying. In addition, after a pre-selected time interval, the first transceiver may transmit again. During the preselected time interval, the second transceiver may exchange information with another transceiver in a time duplex fashion. The processing of the signal at the second transceiver may include estimating the phase differential of the transmitted signal and pre-distorting the transmitted signal. A transceiver includes an encoder for encoding information, a wideband frequency division multiplexer for multiplexing the information onto wideband frequency voice channels, and a local oscillator for upconverting the multiplexed information. The apparatus may include a processor for applying a Fourier transform to the multiplexed information to bring the information into the time domain for transmission.

12 Claims, 23 Drawing Sheets



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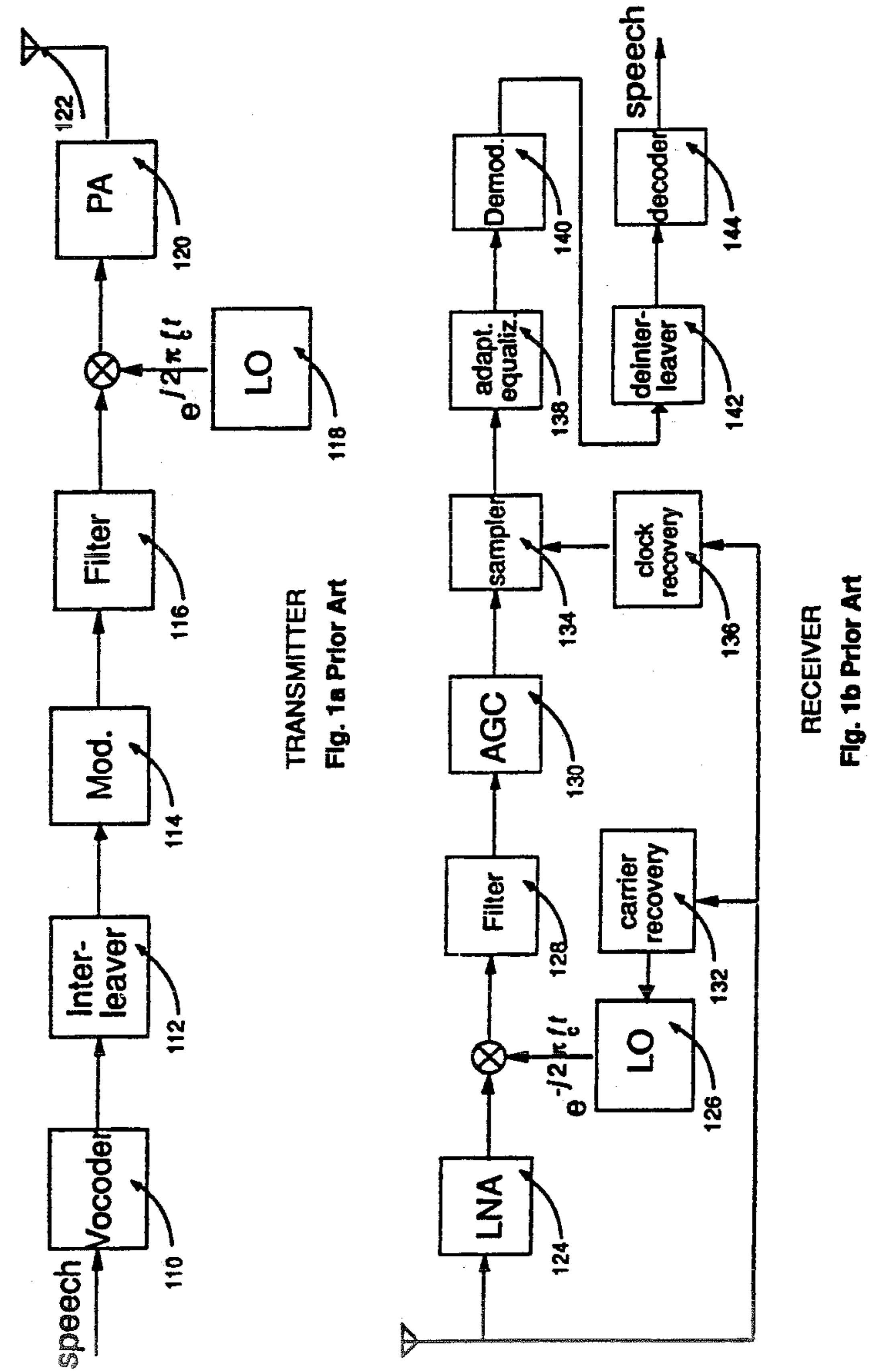


TRANSMITTER
Fig. 1a Prior Art

RECEIVER
Fig. 1b Prior Art

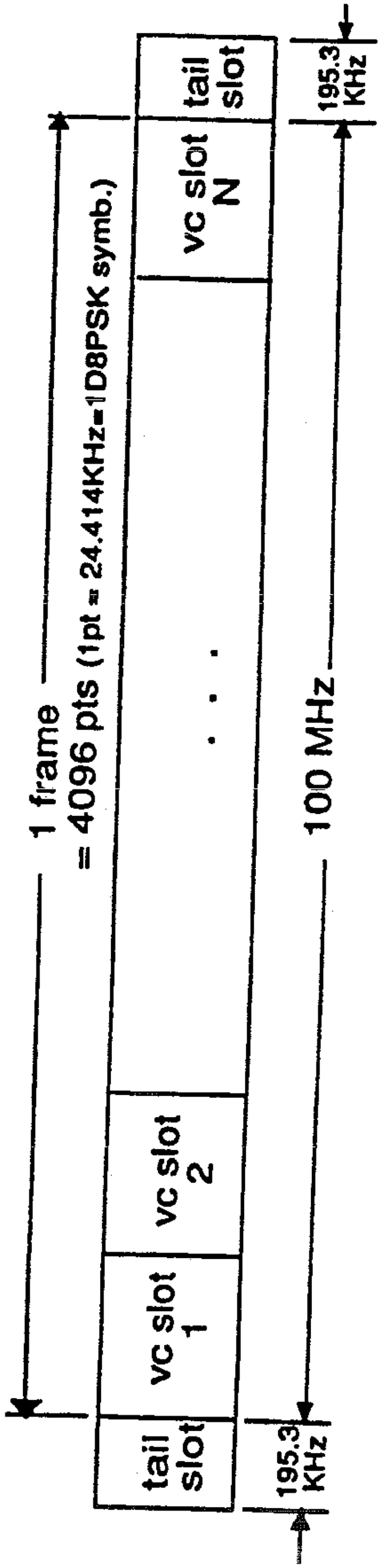

1 frame
= 4096 pts (1pt = 24.414KHz=1D8PSK symb.)
tail slot
vc slot 1
vc slot 2
. . .
vc slot N
tail slot
195.3 KHz
100 MHz
195.3 KHz

Fig. 2

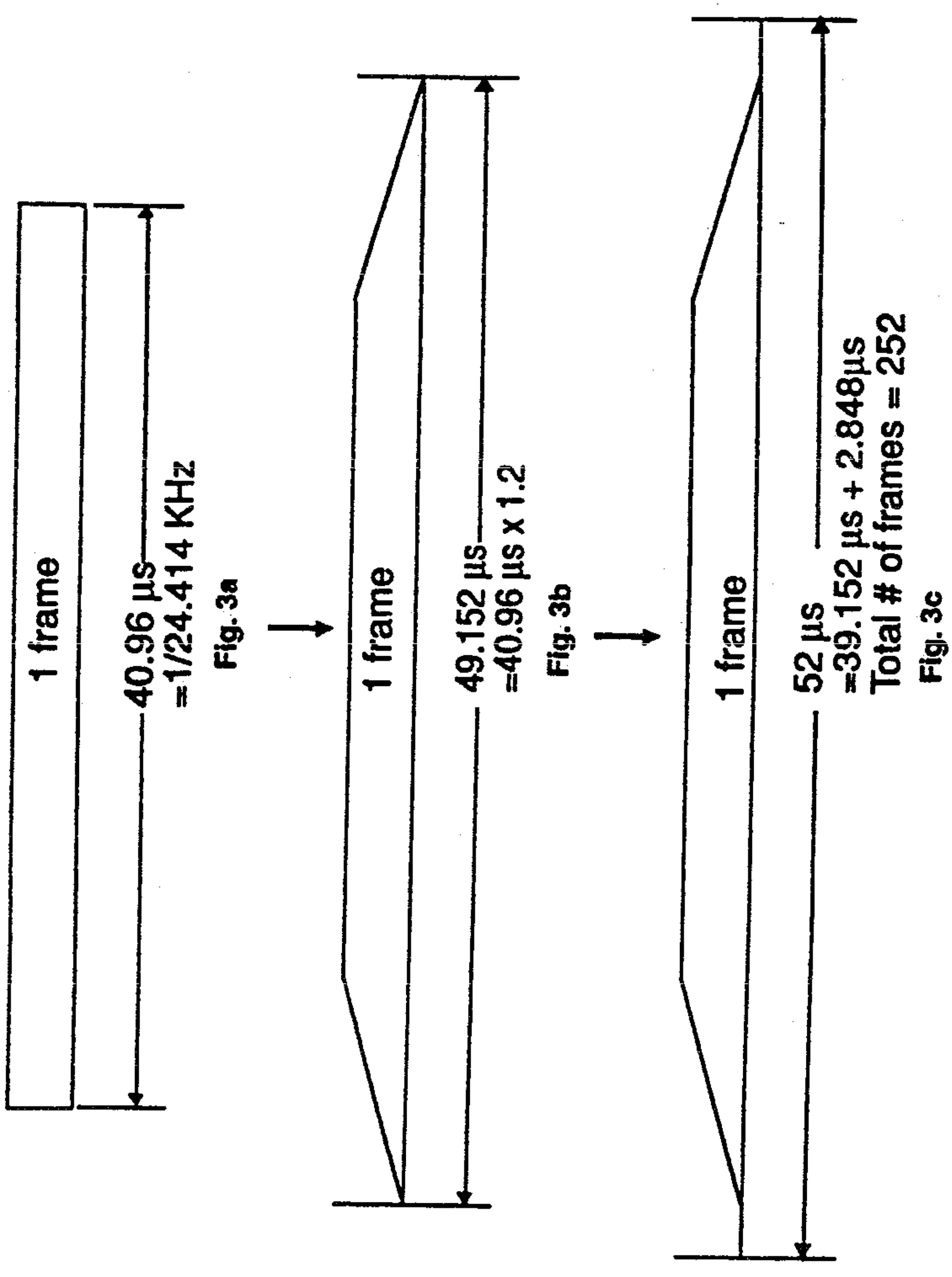


Fig. 3a

Fig. 3b

Fig. 3c

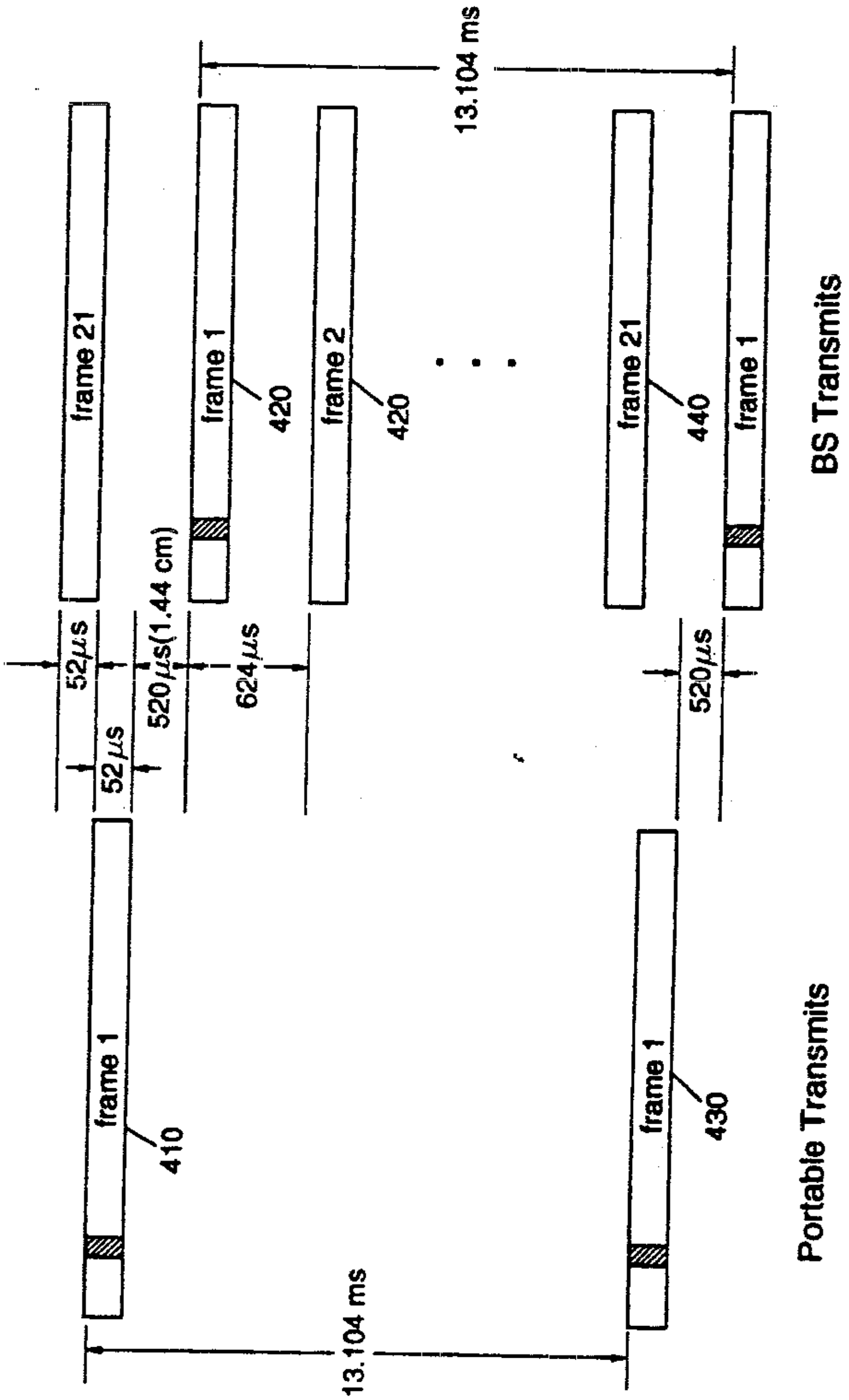
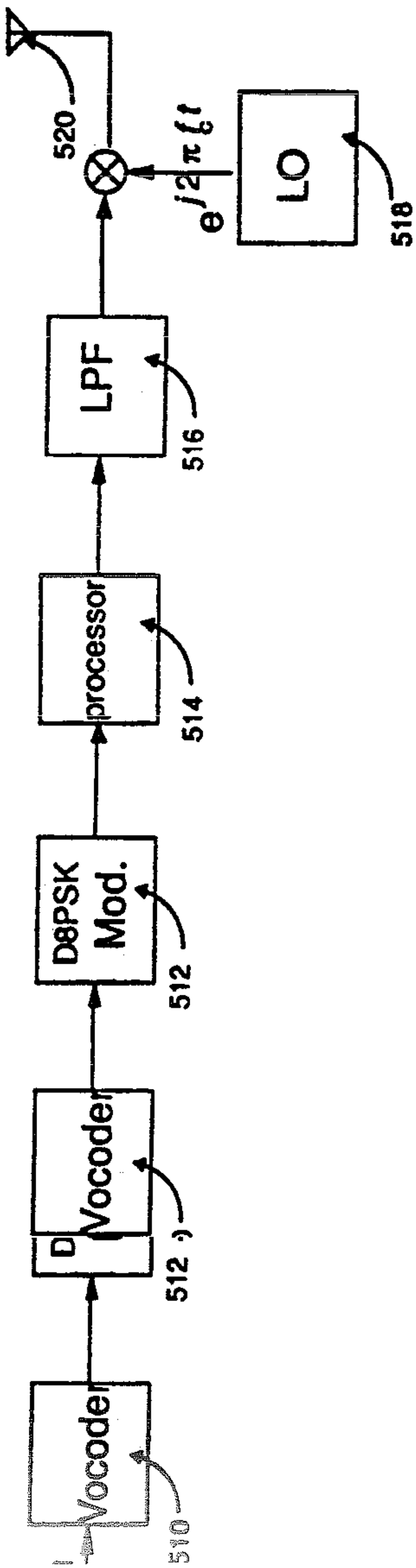
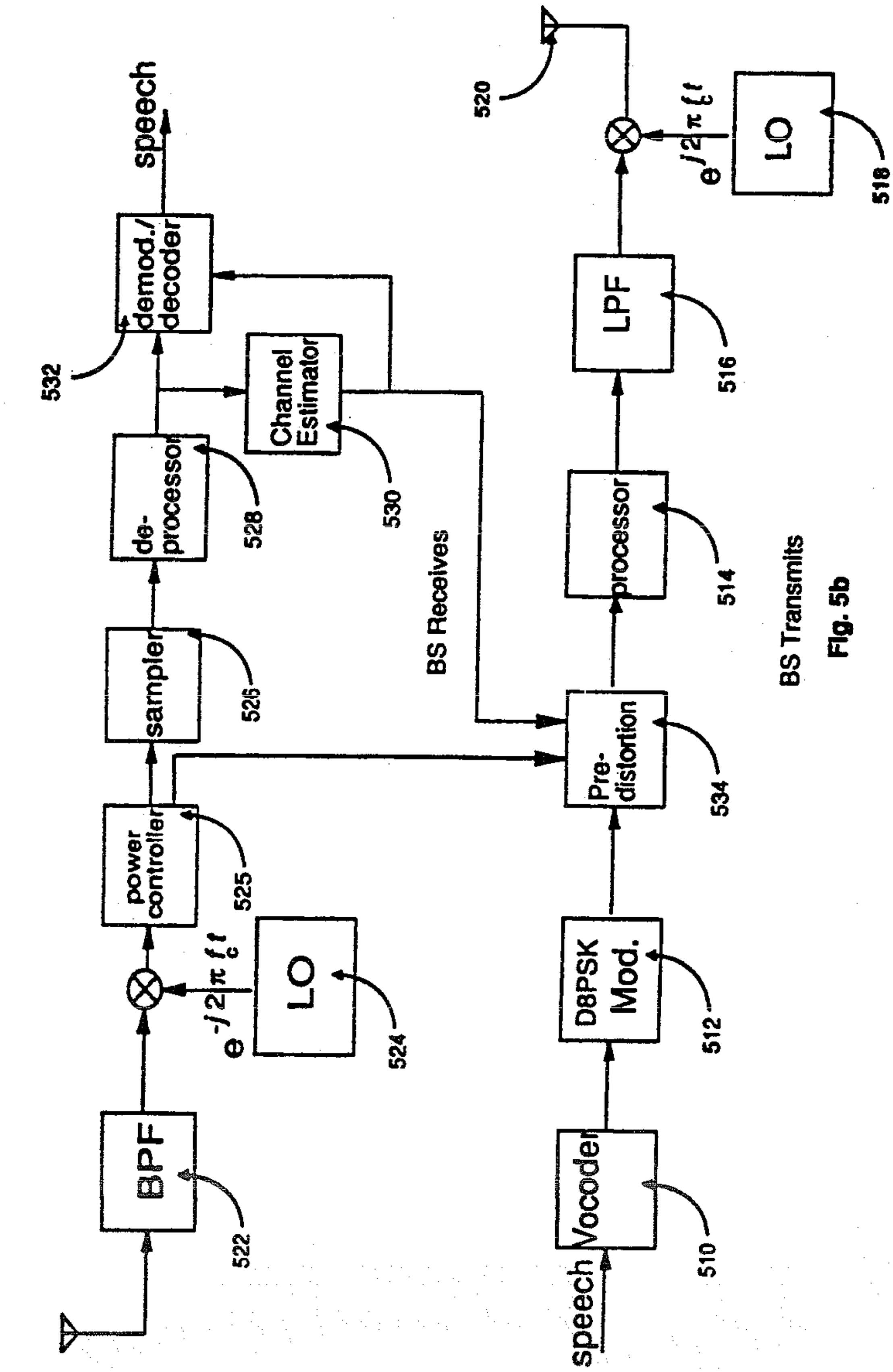

13.104 ms
frame 21
frame 1
420
frame 2
420
frame 21
440
frame 1
BS Transmits
52μs
52μs
520μs(1.44 cm)
624μs
520μs
frame 1
410
frame 1
430
Portable Transmits
13.104 ms

Fig. 4



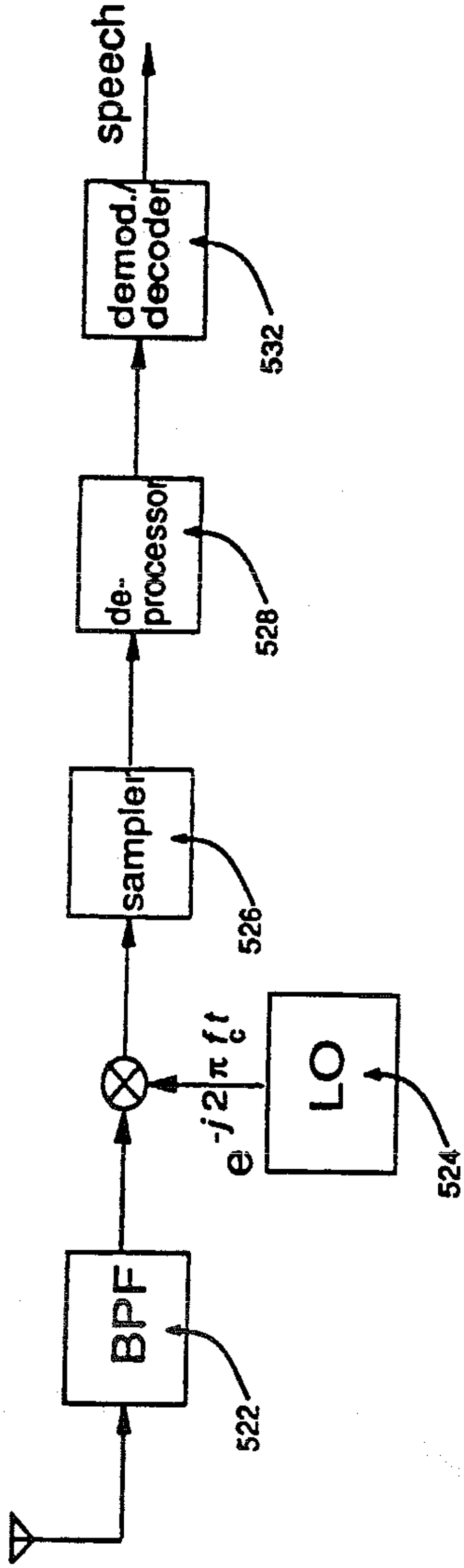
Portable Transmits

Fig. 5a



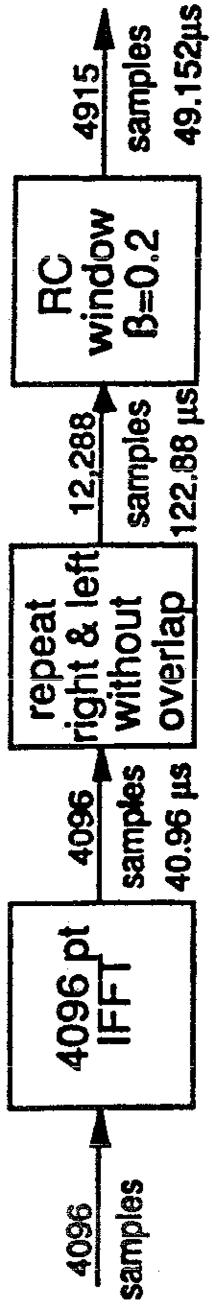
BS Transmits

Fig. 5b



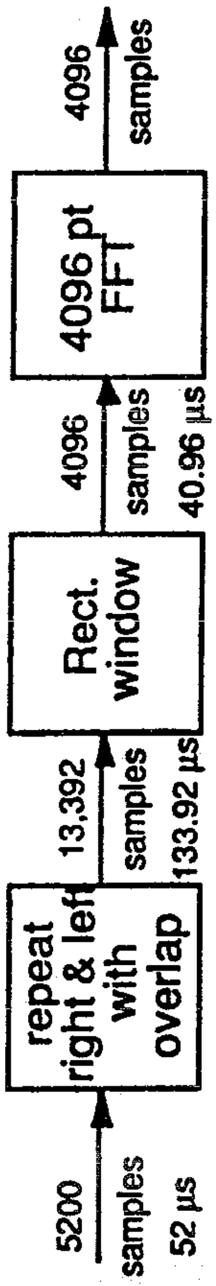
Portable Receives

Fig. 5c



Processor

Fig. 6a



De-processor

Fig. 6b

† a sample above is a complex sample.

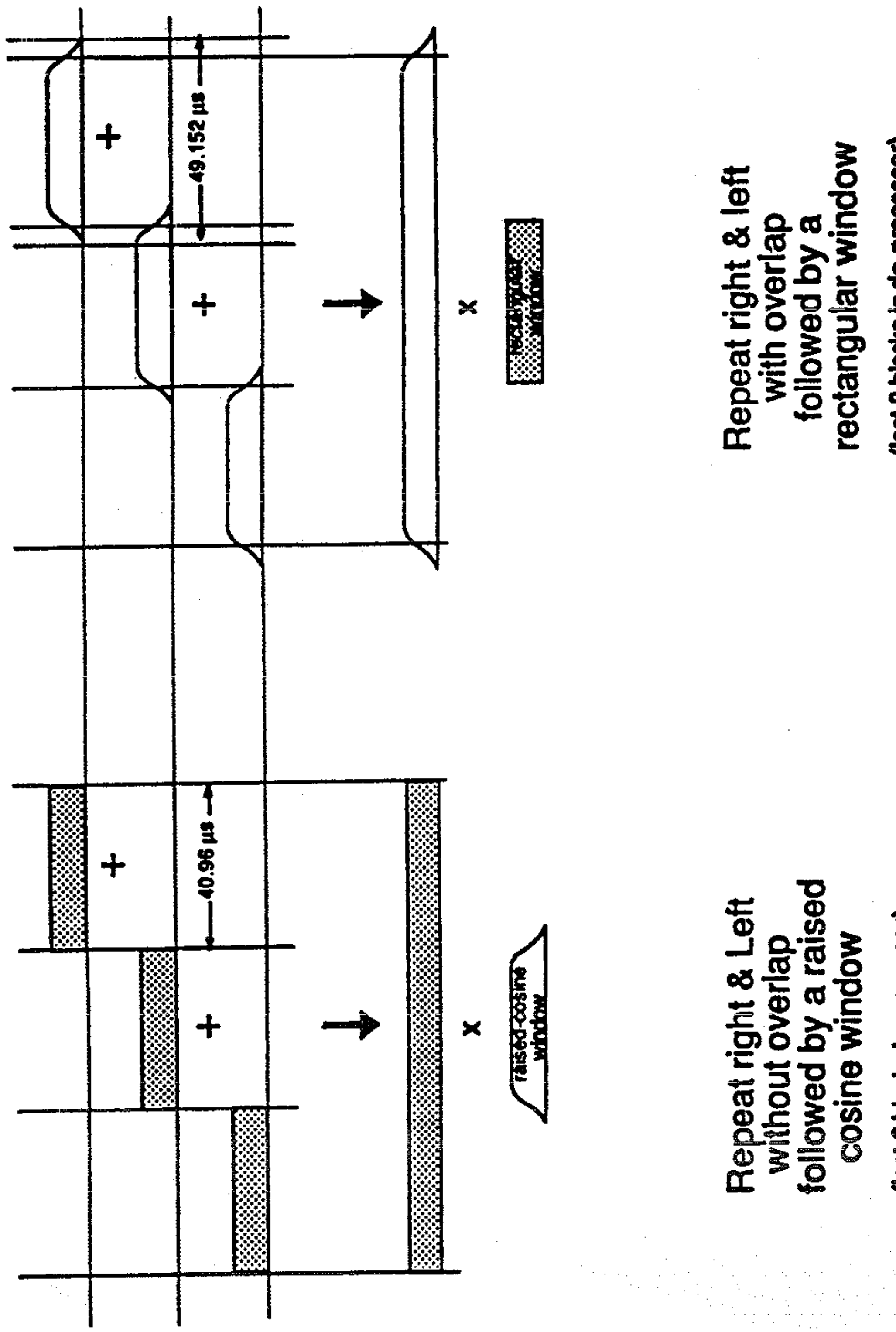

49.152 µs
rectangular window
Repeat right & left
with overlap
followed by a
rectangular window
(last 2 blocks in de-processor)
40.96 µs
raised-cosine window
Repeat right & Left
without overlap
followed by a raised
cosine window
(last 2 blocks in processor)

Fig. 6c

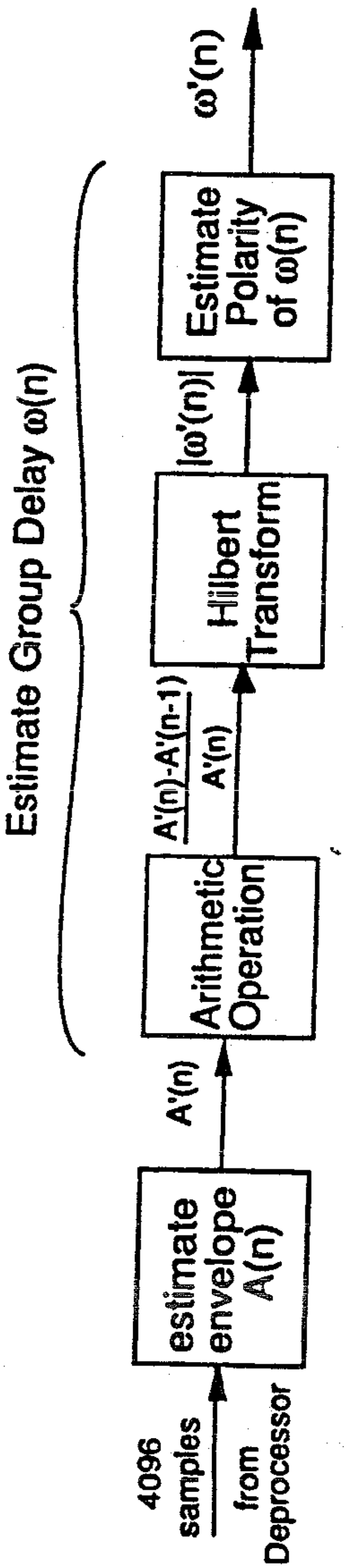

4096 samples from Deprocessor
estimate envelope A(n)
A'(n)
Arithmetic Operation
A'(n)-A'(n-1)
A'(n)
Hilbert Transform
|ω'(n)|
Estimate Polarity of ω(n)
ω'(n)
Estimate Group Delay ω(n)

Fig. 7a

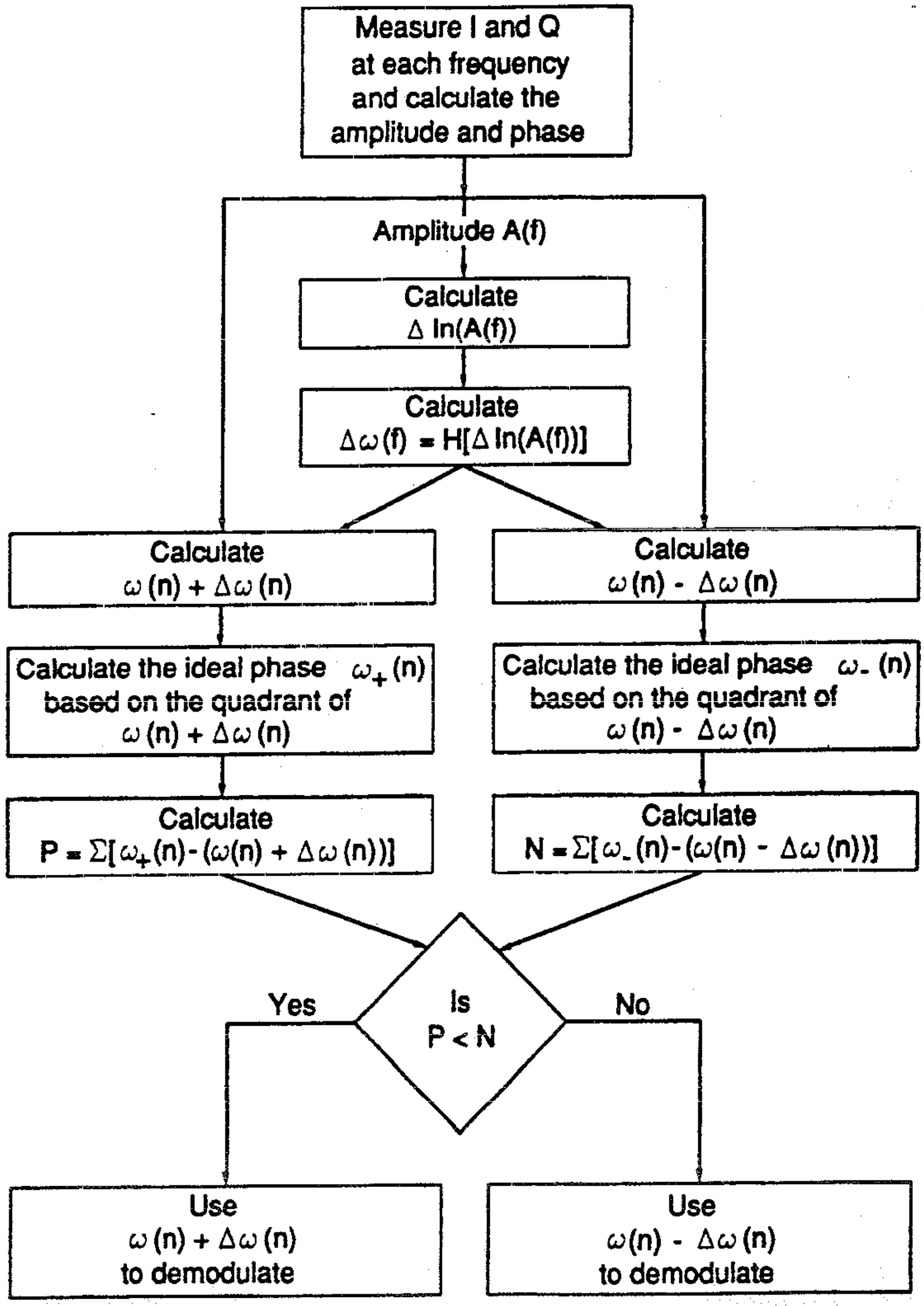

Measure I and Q at each frequency and calculate the amplitude and phase
Amplitude A(f)
Calculate Δ ln(A(f))
Calculate Δω(f) = H[Δ ln(A(f))]
Calculate ω(n) + Δω(n)
Calculate ω(n) - Δω(n)
Calculate the ideal phase ω+(n) based on the quadrant of ω(n) + Δω(n)
Calculate the ideal phase ω-(n) based on the quadrant of ω(n) - Δω(n)
Calculate P = Σ[ω+(n)-(ω(n) + Δω(n))]
Calculate N = Σ[ω-(n)-(ω(n) - Δω(n))]
Is P < N
Yes
No
Use ω(n) + Δω(n) to demodulate
Use ω(n) - Δω(n) to demodulate

Fig. 7b

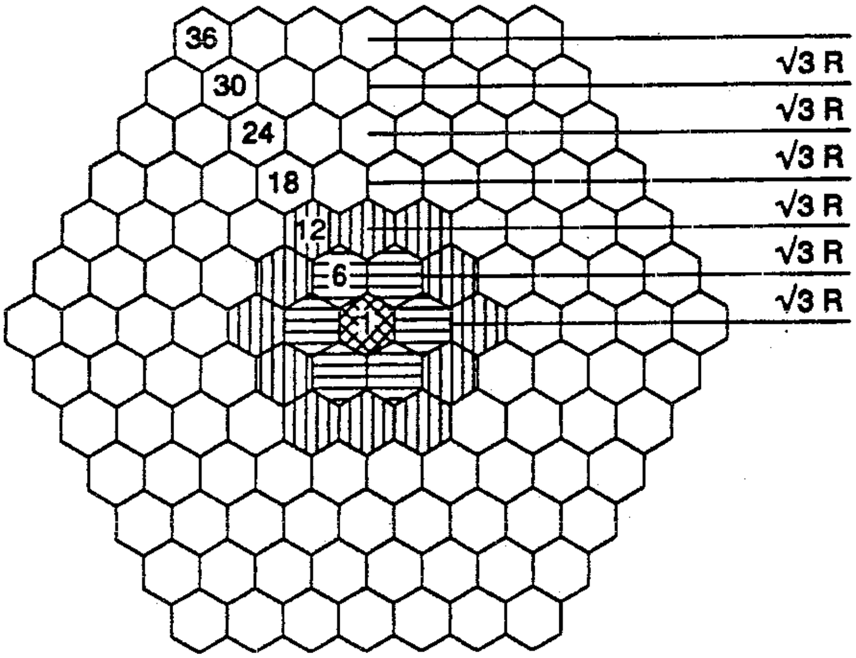


Fig. 8a

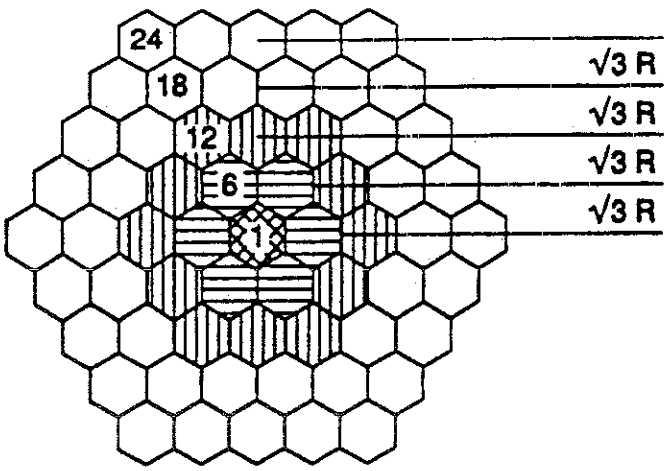


Fig. 8b

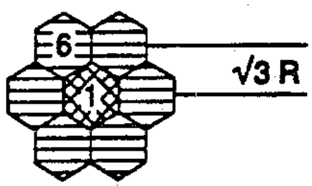


Fig. 8c

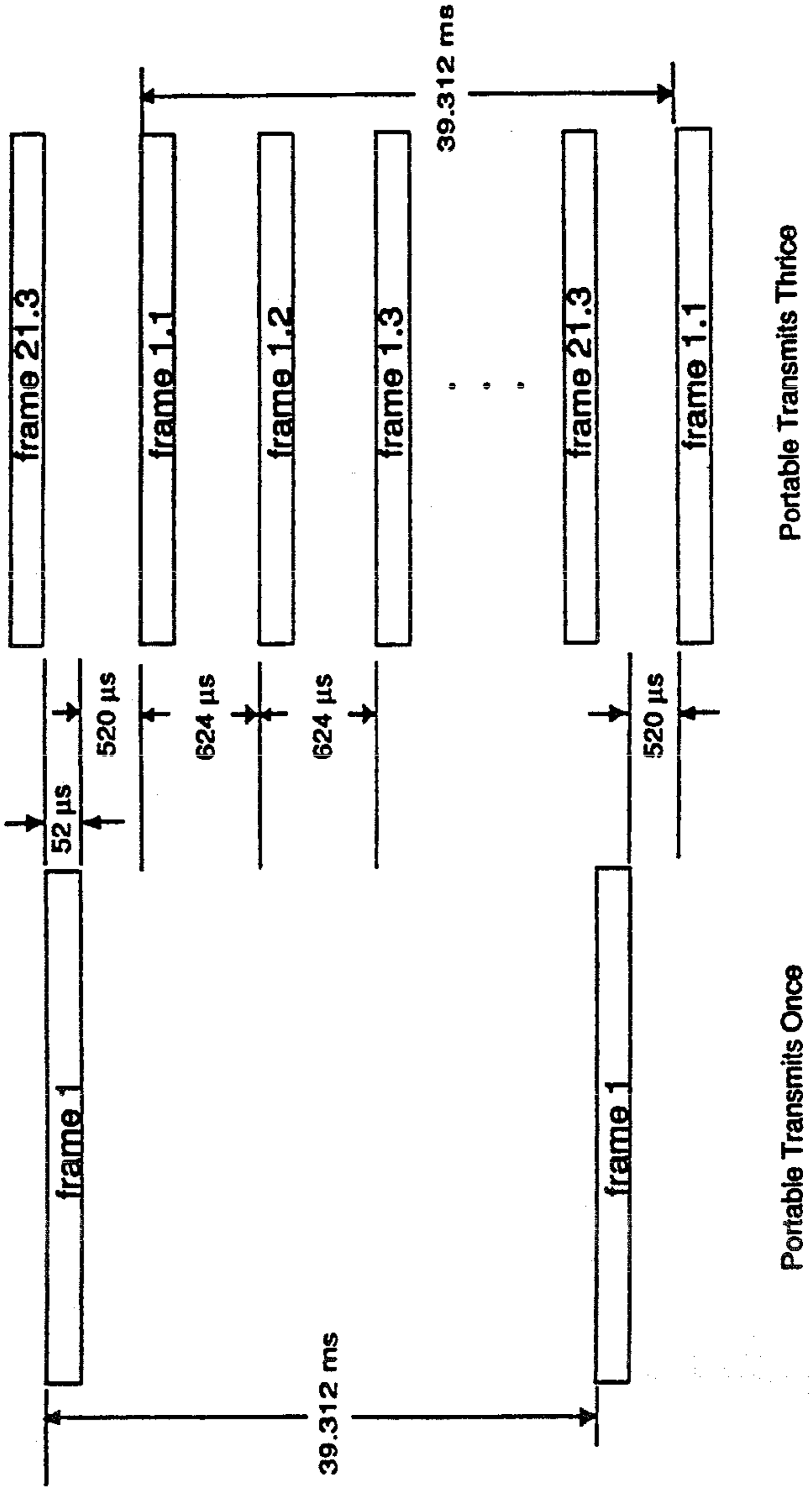

39.312 ms
frame 21.3
frame 1.1
frame 1.2
frame 1.3
. . .
frame 21.3
frame 1.1
Portable Transmits Thrice
52 µs
520 µs
624 µs
624 µs
520 µs
frame 1
frame 1
Portable Transmits Once
39.312 ms

Fig. 9a

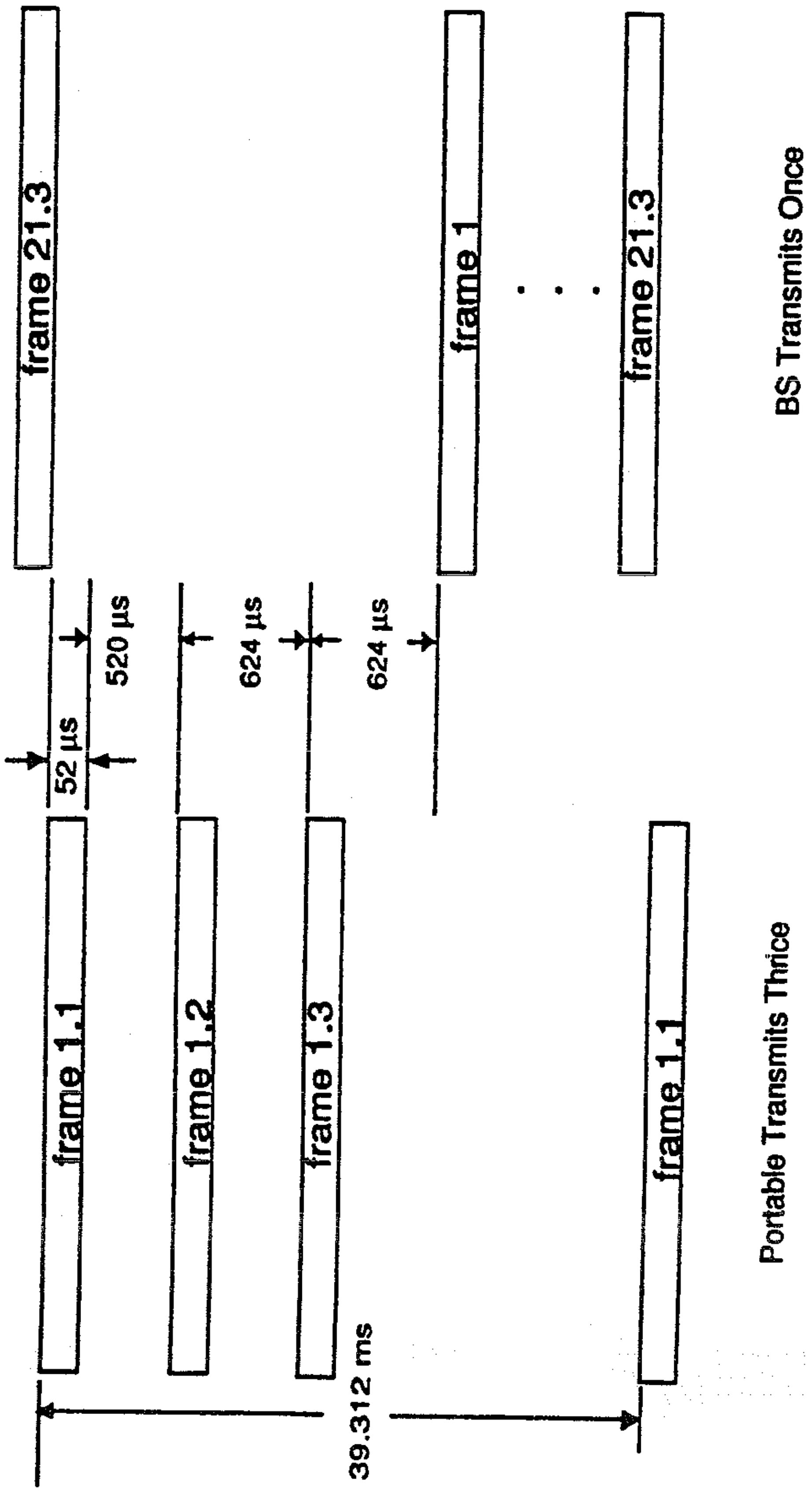
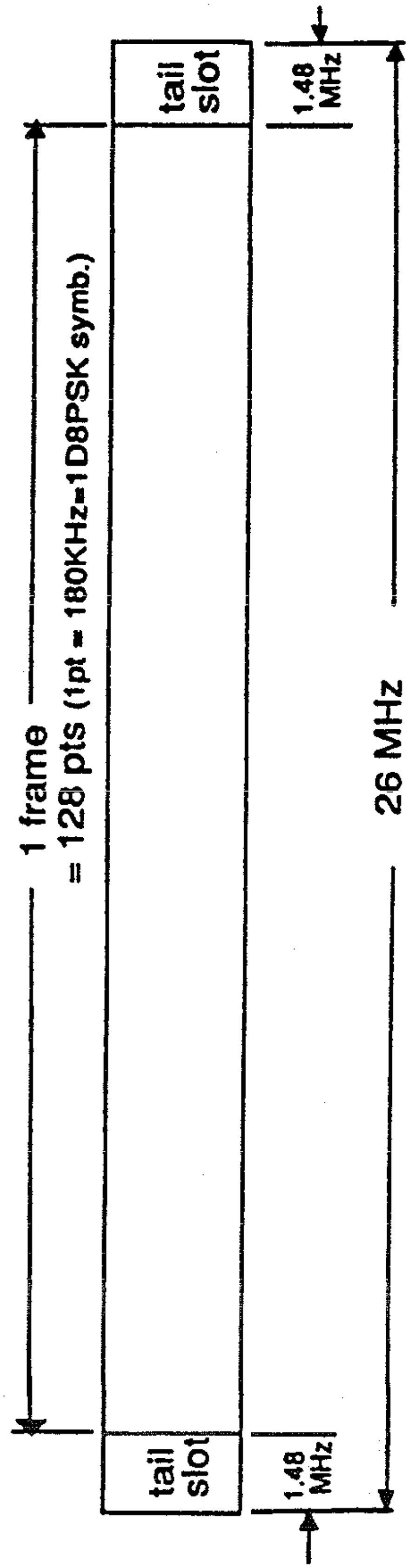

frame 21.3
frame 1
frame 21.3
BS Transmits Once
52 µs
520 µs
624 µs
624 µs
frame 1.1
frame 1.2
frame 1.3
frame 1.1
Portable Transmits Thrice
39.312 ms

Fig. 9b



Wideband OFDM

Fig. 10

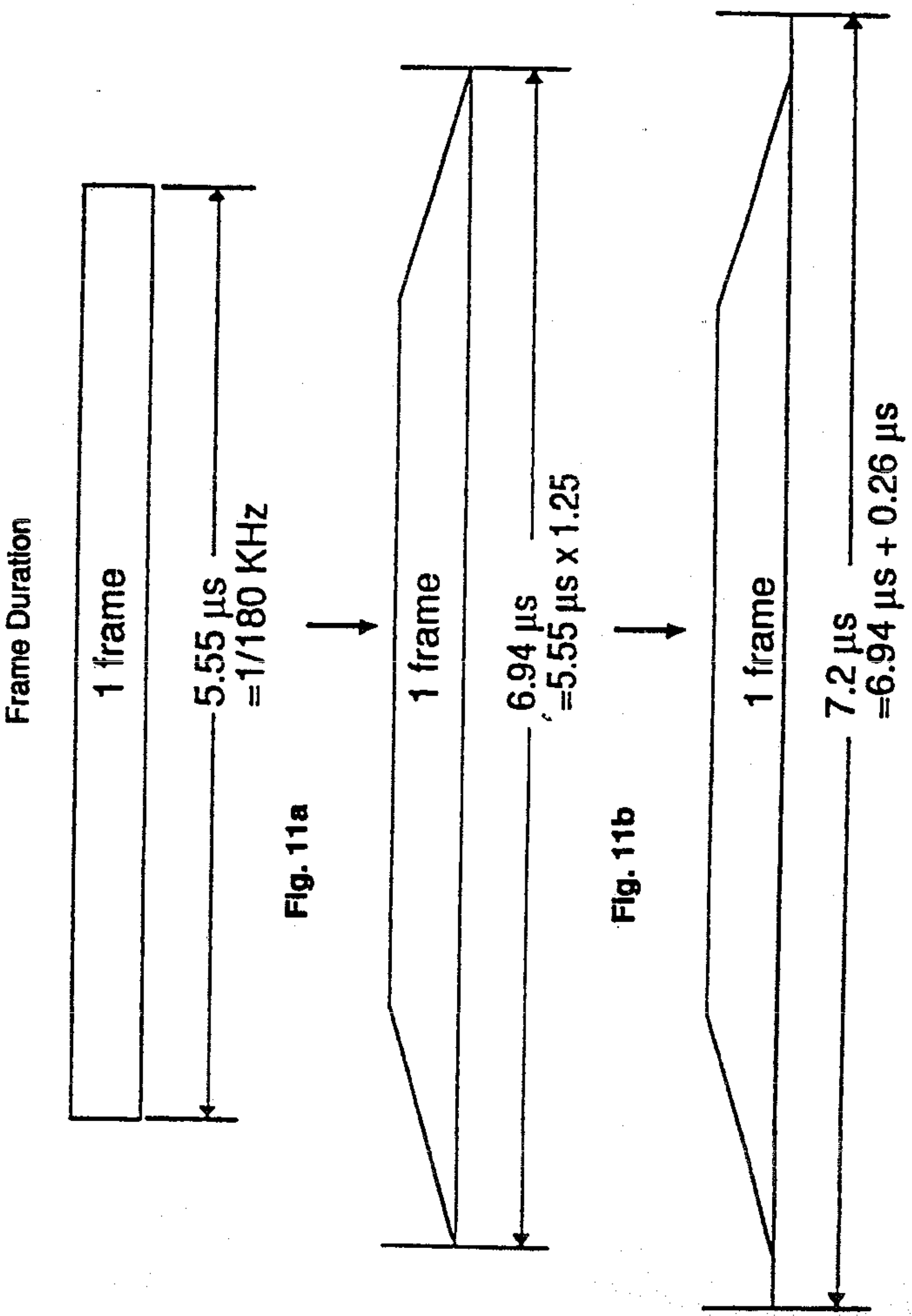


Fig. 11a

Fig. 11b

Fig. 11c

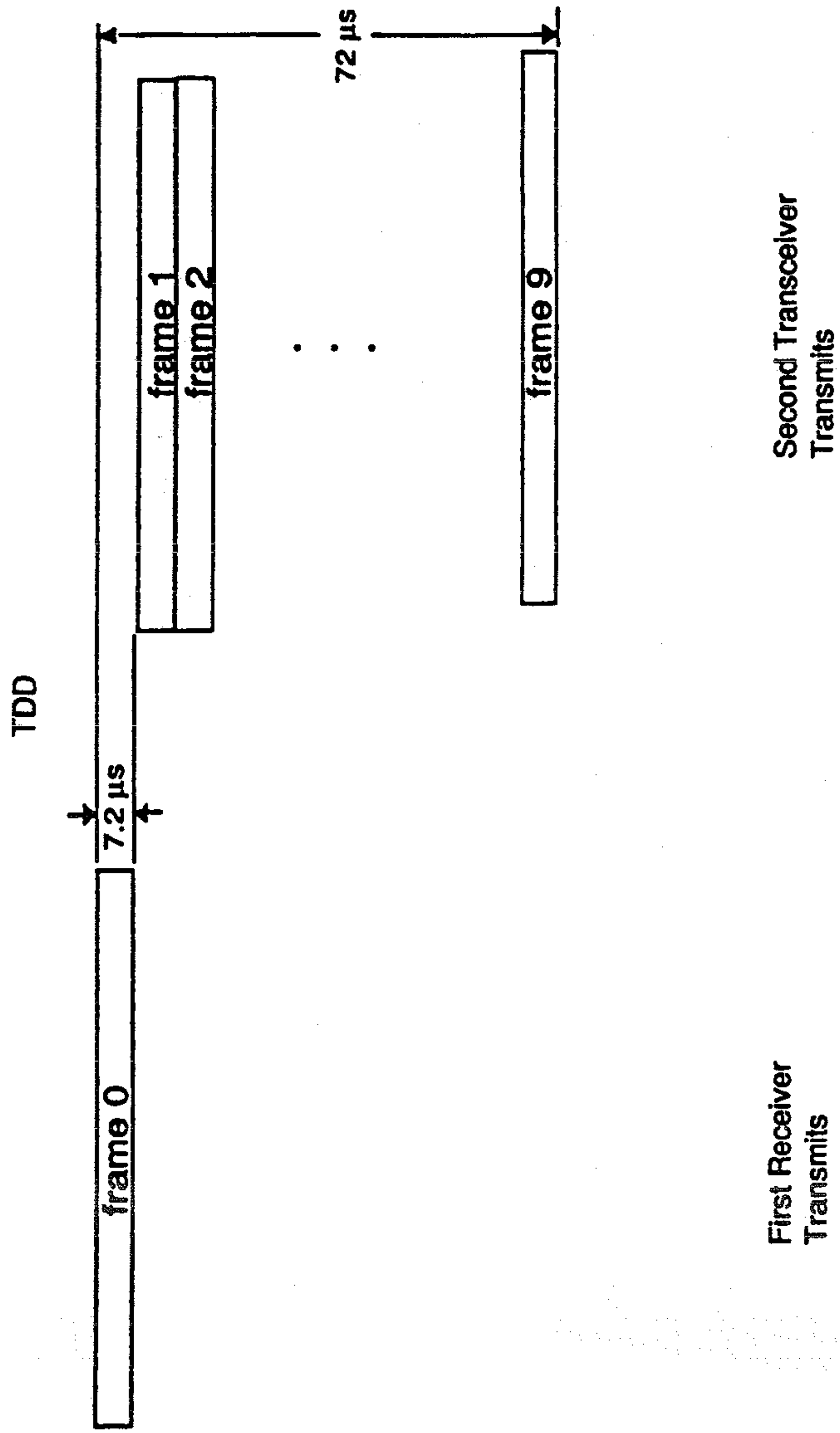
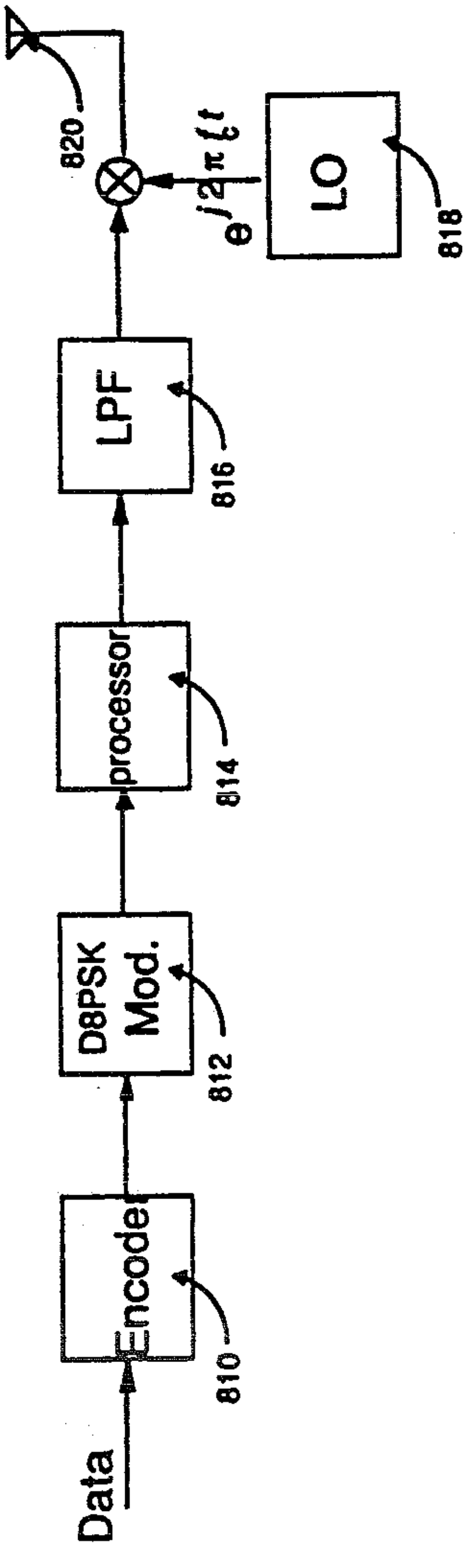

TDD
72 µs
7.2 µs
frame 0
frame 1
frame 2
frame 9
Second Transceiver Transmits
First Receiver Transmits

Fig. 12



First Transceiver Transmits

Fig. 13a

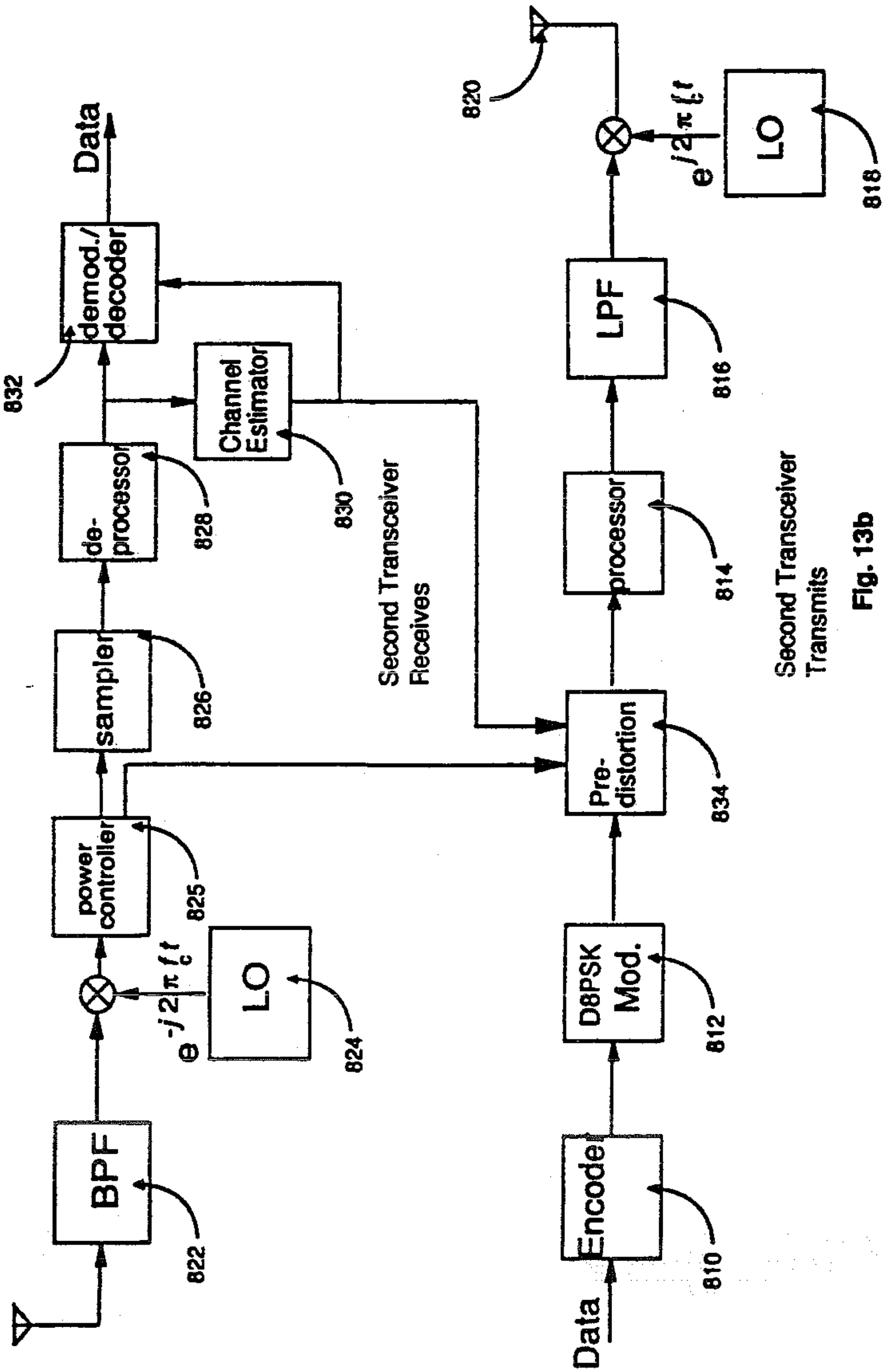
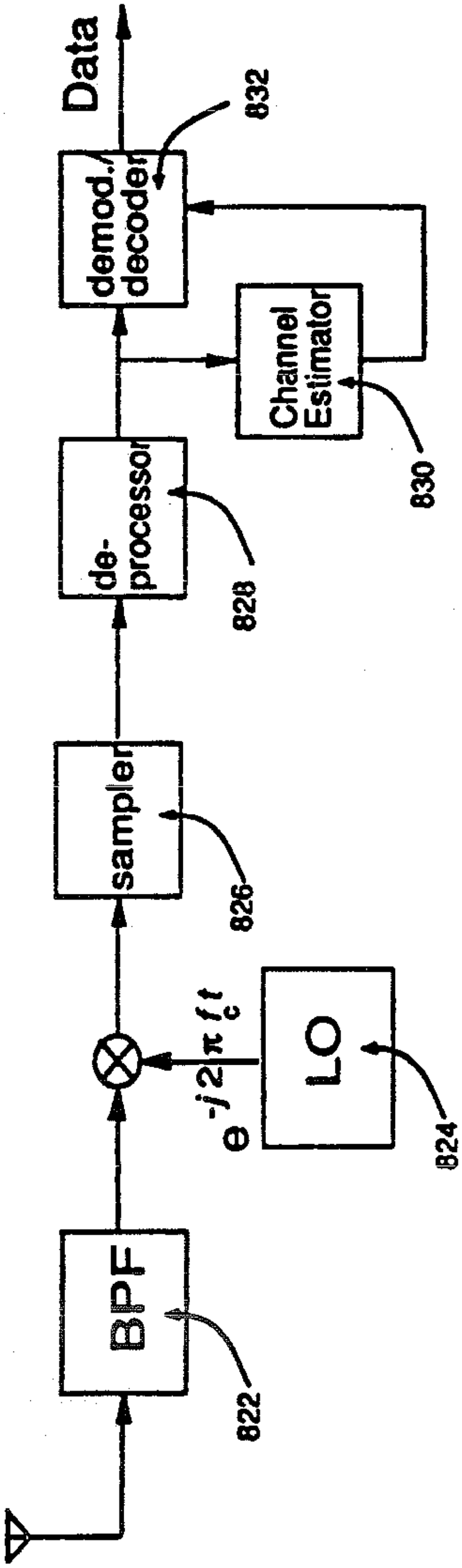

BPF
822
LO
824
$e^{-j2\pi f_c t}$
power controller
825
sampler
826
de-processor
828
Channel Estimator
830
demod./decoder
832
Data
Second Transceiver Receives
Data
Encode
810
D8PSK Mod.
812
Pre-distortion
834
processor
814
LPF
816
LO
818
$e^{j2\pi f_c t}$
820
Second Transceiver Transmits

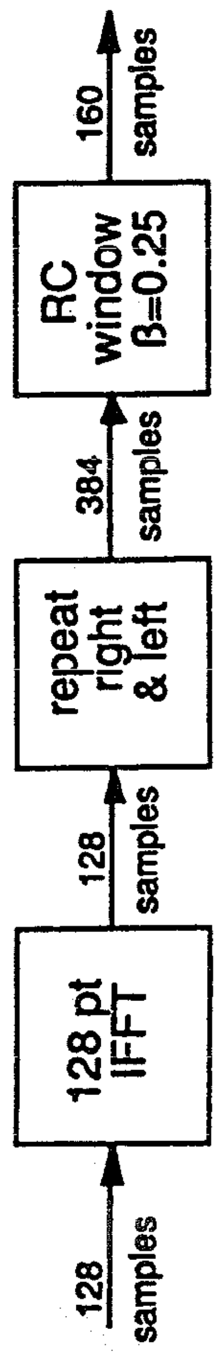
Fig. 13b



First Transceiver Receives

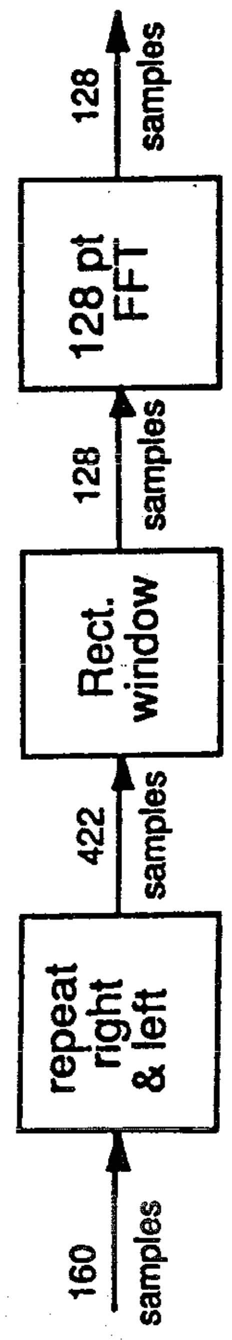
Fig. 13c

Digital Signal Processors



Processor

Fig. 14a



De-Processor

Fig. 14b

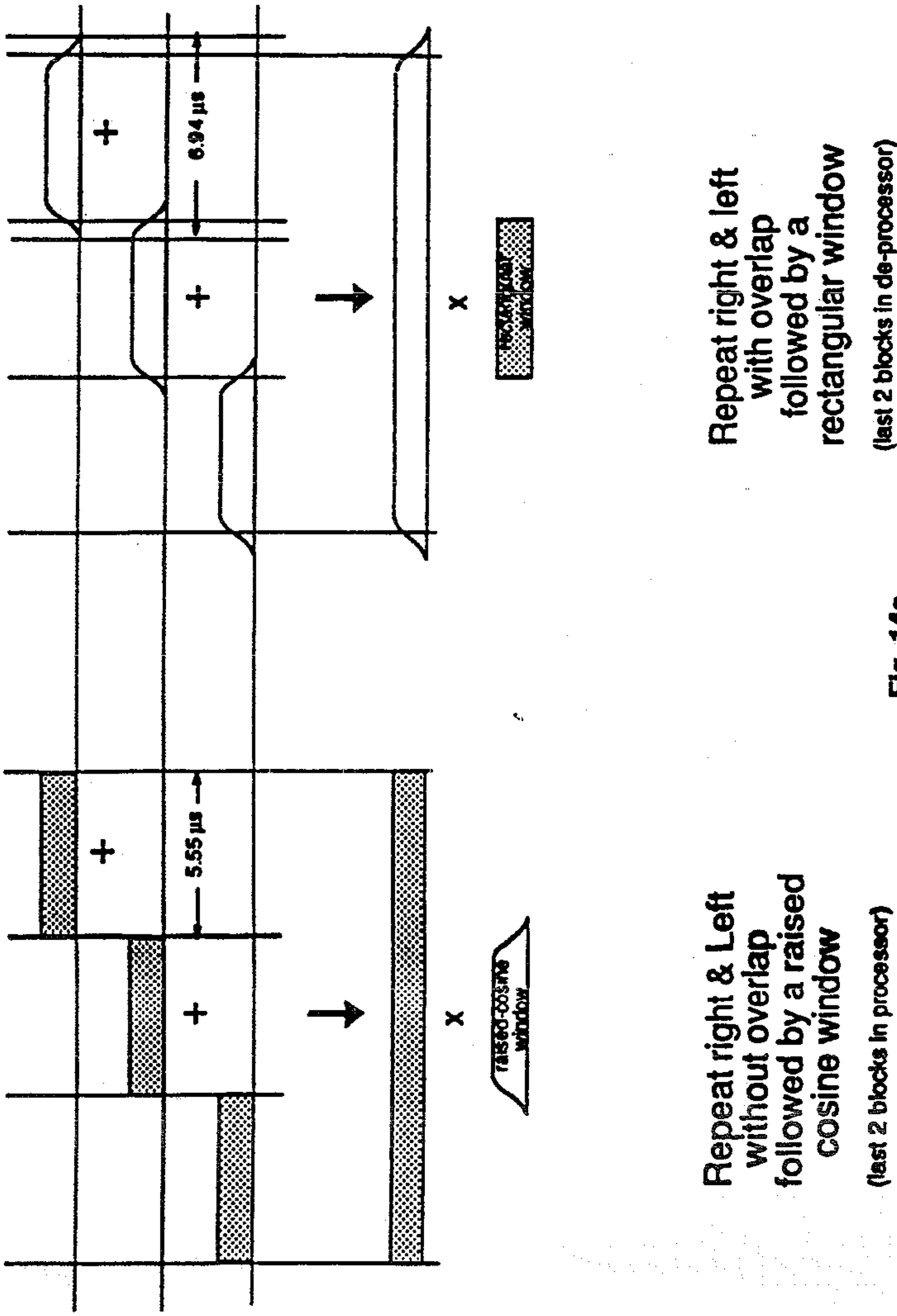

6.94 µs
5.55 µs
x
rectangular window
raised-cosine window
Repeat right & left with overlap followed by a rectangular window
(last 2 blocks in de-processor)
Repeat right & Left without overlap followed by a raised cosine window
(last 2 blocks in processor)

Fig. 14c

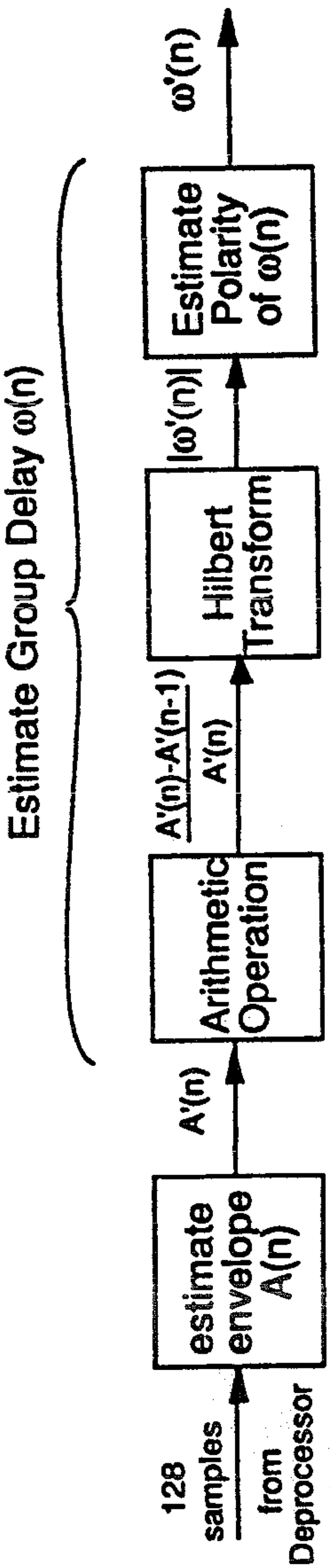

Estimate Group Delay ω(n)
128 samples from Deprocessor
estimate envelope A(n)
A'(n)
Arithmetic Operation
A'(n)-A'(n-1)
A'(n)
Hilbert Transform
|ω'(n)|
Estimate Polarity of ω(n)
ω'(n)

Fig. 15

METHOD AND APPARATUS FOR MULTIPLE ACCESS BETWEEN TRANSCEIVERS IN WIRELESS COMMUNICATIONS USING OFDM SPREAD SPECTRUM

FIELD OF THE INVENTION

This invention relates to voice and data transmission in wireless communications, and particularly between fixed and portable transmitters and receivers.

CLAIM TO COPYRIGHT

BACKGROUND AND SUMMARY OF THE INVENTION

This patent document presents a new multiple access technique for Personal Communication Networks (PCN). Personal communication networks are networks that allow individuals and equipment to exchange information with each other anywhere at anytime through voice, data or video PCN typically include a number of transceivers, each capable of transmitting and receiving information (voice, data or video) in the form of electromagnetic signals The transceivers may be fixed or portable, and may be identical or one or more of them may be more complex

The system must allow the transceivers to access each other to enable the exchange of information. When there are a number of transceivers, multiple access, that is, access by more than one transceiver to another transceiver, must be allowed.

One of the constraints of designing a PCN is that a transceiver, or portable radio unit, must be small in size. The smaller the unit, the better for portability. The small size of the units means only small and light-weight power sources can be used If the portable is to be used for any length of time, it must therefore consume minimal power.

Also, to allow use of the radio frequency spectrum without obtaining a license in North America, the system must use a spread spectrum and satisfy federal regulations. In part, these regulations impose limits on the power and the frequency spread of the signals exchanged between the transceivers. An object of an aspect of this invention is to satisfy those requirements.

Also, transceivers talk to each other over a fixed bandwidth. Because of the limited availability of the RF spectrum, the system must be bandwidth efficient yet at the same time maintain high quality exchange of information at all times in one of the most hostile channels known in communication. The new multiple access technique proposed here addresses all these issues.

The new access technique has a low Bit Error Probability (BER) as well as a low probability of dropped and blocked calls. This is due to the fact that the access technique is robust against multipath, Doppler shifts, impulse noise and narrowband interference It has a low

cochannel interference and little or no intersymbol interference.

The new access technique can offer up to 38 times the capacity of analog FM It includes in one aspect wideband orthogonal frequency division multiplexing of the information to be exchanged, and may include slow Frequency Hopping (FH). The technique is implemented using Digital Signal Processors (DSP) replacing conventional analog devices. The system operates with relatively small cells. In other aspects, dynamic channel allocation and voice activation may be used to improve the capacity of the system.

Advantages of the present invention include:

1. It can be used indoors as well as outdoors using the same transceivers. If data is to be exchanged, as opposed to voice, the transceiver preferably contains an estimator to allow pre-distortion and post-distortion of the transmitted signal.
2. The system, as compared with prior art systems omits the clock or carrier recovery, automatic gain control or passband limiter, power amplifier, an equalizer or an interleaver-deinterleaver, and therefore has low complexity.
3. The system offers good speech quality, as well as low probabilities of dropped and blocked calls It is robust against Doppler and multipath shifts. It is also robust against both impulse noise and narrowband interference.
4. The system is flexible, such that at the expense of increased complexity of the DSP receiver it can be applied over noncontiguous bands. This is accomplished by dividing a 100 MHz (in one of the exemplary embodiments described here) band into several subbands each accommodating an integer number of voice channels.
5. The system offers low frame delay (less than 26.2 ms in the exemplary cellular embodiment described here) The transceiver requires low average transmitted power (of the order of 20 μW in the exemplary cellular embodiment described here) which means power saving as well as enhanced biological safety.
6. The system offers up to a 38 fold increase in capacity over the North American Advanced Mobile Phone System (AMPS) which uses analog frequency modulation.

Operation of the system in accordance with the techniques described in this disclosure may permit compliance with technical requirements for spread spectrum systems.

There is therefore disclosed in one aspect of the invention a method for allowing a number of wireless transceivers to exchange information (data, voice or video) with each other. In the method, a first frame of information is multiplexed over a number of frequency bands at a first transceiver, and the information transmitted to a second transceiver. In a cellular implementation, the second transceiver may be a base station with capacity to exchange information with several other transceivers. The information is received and processed at the second transceiver. The frequency bands are selected to occupy a wideband and are preferably contiguous, with the information being differentially encoded using phase shift keying.

A signal may then be sent from the second transceiver to the first transceiver and de-processed at the first transceiver. In addition, after a preselected time interval, the first transceiver transmits again. During

the preselected time interval, the second transceiver may exchange information with another transceiver in a time duplex fashion.

The processing of the signal at the second transceiver ma include estimating the phase differential of the transmitted signal and predistorting the transmitted signal.

The time intervals used by the transceivers may be assigned so that a plurality of time intervals are made available to the first transceiver for each time interval made available to the second transceiver while the first transceiver is transmitting, and for a plurality of time intervals to be made available to the second transceiver for each time interval made available to the first transceiver otherwise. Frequencies may also be borrowed by one base station from an adjacent base station. Thus if one base station has available a first set of frequencies, and another a second set of distinct frequencies, then a portion of the frequencies in the first set may be temporarily re-assigned to the second base station.

In an implementation of the invention for a local area network, each transceiver may be made identical except for its address.

Apparatus for carrying-out the method of the invention is also described here. The basic apparatus is a transceiver which will include an encoder for encoding information, a wideband frequency division multiplexer for multiplexing the information onto wideband frequency voice channels, and a local oscillator for upconverting the multiplexed information. The apparatus may include a processor for applying a Fourier transform to the multiplexed information to bring the information into the time domain for transmission

BRIEF DESCRIPTION OF THE DRAWINGS

There will now be described a preferred embodiment of the invention, with reference to the drawings, by way of illustration, in which like numerals denote like elements and in which:

FIGS 1*a* and 1*b* are schematics of a prior art receiver and transmitter respectively;

FIG. 2 is a schematic showing the use of the available frequencies according to one aspect of the invention for use with cellular applications;

FIG. 3*a* is a schematic showing an idealized pulse for transmission over a cellular system;

FIG. 3*b* is a schematic showing a modified version of the pulse shown in FIG. 3*a*;

FIG. 3*c* is a schematic showing a further modified version of the pulse shown in FIG. 3*a*;

FIG. 4 is a schematic showing an exemplary protocol for cellular communication;

FIG. 5*a* is a block diagram showing the structure and function of an embodiment of the transmitter of a cellular portable in accordance with the invention;

FIG. 5*b* is a block diagram showing the structure and function of an embodiment of the transmitter and receiver of a cellular base station in accordance with the invention;

FIG. 5*c* is a block diagram showing the structure and function of an embodiment of the receiver of a cellular portable in accordance with the invention;

FIG. 6*a* is a flow diagram showing the function of the processor in either of FIGS. 5*a* or 5*b*;

FIG. 6*b* is a schematic showing the function of the deprocessor in either of FIGS. 5*b* or 5*c*;

FIG. 6*c* is a schematic further illustrating the operation of the processor and deprocessor shown in FIGS. 6*a* and 6*b*;

FIG. 7*a* is a schematic showing the structure and function of the channel estimator in FIG. 5*b*;

FIG. 7*b* is a flow chart showing the operation of the channel estimator of FIGS. 5*b* and 7*a*;

FIGS. 8*a*, 8*b* and 8*c* are respectively schematics of 126, 63 and 7 cell reuse patterns;

FIGS. 9*a* and 9*b* are schematics showing transmit protocols according to one aspect of the invention;

FIG. 10 is a schematic showing the use of the available frequencies according to another aspect of the invention for use with local area network applications;

FIG. 11*a* is a schematic showing an idealized pulse for transmission over a local network system;

FIG. 11*b* is a schematic showing a modified version of the pulse shown in FIG. 11*a*;

FIG. 11*c* is a schematic showing a further modified version of the pulse shown in FIG. 11*a*;

FIG. 12 is a schematic showing a preferred protocol for local area network communication;

FIG. 13*a* is a block diagram showing the structure and function of an embodiment of the transmitter of a local area network transceiver according to the invention;

FIG. 13*b* is a block diagram showing the structure and function of an embodiment of a further local area network transceiver according to the invention;

FIG. 13*c* is a block diagram showing the structure and function of an embodiment of the receiver of a local area network transceiver according to the invention;

FIG. 14*a* is a flow diagram showing the function of the processor in either of FIGS 13*a* or 13*b*;

FIG. 14*b* is a schematic showing the function of the deprocessor in either of FIGS. 13*b* or 13*c*;

FIG 14*c* is a schematic further illustrating the operation of the processor and deprocessor shown in FIGS. 14*a* and 14*b*; and

FIG. 15 is a schematic showing the structure and function of the channel estimator in FIG. 13*b*.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Introduction

The benefits of the invention can be readily appreciated with reference to FIG. 1, which shows a prior art transmitter/receiver configuration for a portable unit. The transmitter includes a vocoder 110, an interleaver 112, a modulator 114, a filter 116, local oscillator 118, power amplifier (PA) 120 and antenna 122. The receiver includes an LNA 124, a local oscillator 126, a filter 128, automatic gain control (AGC) 130 with an associated passband hardlimiter not separately shown, carrier recovery 132, sampler 134, clock recovery 136, adaptive (or fixed) equalizer 138, demodulator 140, deinterleaver 142 and decoder 144. With implementation of the present invention, several of the blocks shown in FIG. 1 are not required. These are the interleaver 112, deinterleaver 142, power amplifier 120, automatic gain control 130 with passband hard-limiter, clock recovery 136 and carrier recovery 132, and the equalizer 138. It will now be explained how the proposed system obtains the omission of these blocks without impairing the quality and capacity of the system.

In this disclosure there will be described two systems as examples of the implementation of the invention. The system described first here will apply to a cellular system with a number of portable transceivers and base stations (BS). Then will be described a local area net-

work implementation. A local area network will typically be a system of equal transceivers. The invention may also be implemented with combinations of cellular and local area networks, or to a system with a number of equal transceivers and a master or controlling transceiver. "Equal" as used here means that the transceivers have more or less the same processing equipment and processing capabilities. The system described here is primarily for the exchange of voice information.

Link set-up and termination protocols between transceivers, and the equipment required to implement them, are well understood in the art as well as the basic structure of radio transceivers that may be used to implement the invention. Hence these elements are not described here. What is described here are the novel operational, functional and structural elements that constitute the invention.

Cellular Implementation of Wideband Modulation

The present invention proposes in one embodiment a wideband modulation scheme for exchange of information between transceivers such as portables and base stations.

Wideband in this patent document is described in the context of Wideband-Orthogonal Frequency Domain Modulation (W-OFDM or wideband OFDM). In OFDM, the entire available bandwidth B is divided into a number of points K, where adjacent points are separated by a frequency band Δf, that is $B=K\Delta f$. The K points are grouped into a frame of K_1 points and two tail slots of K_2 points each, so that $K=K_1+2K_2$. The frame carries the information intended for transmission under the form of multilevel differential phase shift keying (MDPSK) symbols or differential quadrature amplitude modulated (DQAM) symbols. Thus each point in the frame corresponds to one information symbol. The two tail slots act as guard bands to ensure that the out-of-band signal is below a certain power level. For example, when a pulse P(f) is selected for pulse shaping and the out-of-band signal has to be ydB or less relative to the in-band signal, K_2 is selected such that

$$20.\log_{10}|P(f)/P(0)| \leq y \text{ for } f \geq K_2\Delta f.$$

When the pulse is a raised-cosine pulse with a roll-off β and when the number of levels each symbol can take is M, the bit rate is equal to $K_1\log_2M/(\delta t+(1+\beta)/\Delta f)$ where $(1+\beta)/\Delta f$ is the duration of the frame and δt is the guard time required to take into account the delay of arrival and the delay spread due to multipath. In this case, the bandwidth efficiency, which is defined as the ratio between the bit rate and the bandwidth, is equal to:

$$\log_2M/((1+\beta+\delta t\Delta f)(1+2K_2/K_1))$$

In wideband-OFDM, both K and Δf are selected sufficiently large to achieve a high throughput as well as to reduce the effects on the BER of the clock error, the Doppler shift and the frequency offset between the LO in the transmitter and the one in the receiver. To show what is meant by "K and Δf are selected sufficiently large", consider the effect of increasing K and Δf on (1) the clock error, (2) the Doppler shift and (3) the frequency offset between the LO in the transmitter and the LO in the receiver.

(1) When a clock error at a transceiver of value τ occurs in the time domain, it causes a shift in the phase difference between adjacent symbols in the frequency domain of value $2\pi\Delta f\tau$. When τ is equal to χT where T is duration of one time domain sample and χ is any real value, the shift is equal to $2\pi\Delta f\chi T$. Hence, τ causes a shift in the phase difference between adjacent symbols of value $2\pi\chi/K_1$ since T is equal to $1/(K_1\Delta f)$. By doubling the number of symbols from K_1 to $2K_1$ the shift in the phase difference is reduced by half from $2\pi\chi/K_1$ to $\pi\chi/K_1$. Thus, the effect of the clock error on the BER is reduced by increasing K.

(2) When there is relative motion between the transmitting transceiver and the receiving transceiver, a Doppler shift occurs with a maximum absolute value $|V/\lambda|$ where V is the relative velocity between the two transceivers and λ is the wavelength of the travelling wave corresponding to the carrier frequency f_c (i.e. f_c is the frequency corresponding to the middle point in the frame). Such a Doppler shift causes a sampling error in the frequency domain of the same amount, or equivalently, it causes a sampling error of $V/(\lambda\Delta f)$ relative to one symbol sample. Thus, the effect of the Doppler shift on the BER is reduced by increasing Δf.

(3) When a frequency offset between the LO in the transmitter and the one in the receiver occurs with a value f_o, it causes a sampling error in the frequency domain of the same amount, or equivalently, it causes a sampling error of $f_o/\Delta f$ relative to one symbol sample. Thus, the effect on the BER of the frequency offset between the LO in transmitter and the one in the receiver is reduced by increasing Δf.

In summary, OFDM with a K and a Δf large enough to be able to achieve a specific throughput and large enough to be able to avoid using either a clock or a carrier recovery device without substantially affecting the BER is referred to here as Wideband-OFDM. As an example, let us assume that MDPSK is used in an OFDM system with the number M of levels, with a carrier frequency f_c, with a raised cosine pulse of roll-off β, with the LO at the receiver having a frequency offset f_o relative to the LO at the transmitter (so that the frequency offset between the carrier frequencies in the first and second transceivers of the multiplexed information is f_o), with a given maximum expected clock error $\tau=\chi T$ at the receiving transceiver, where T is the duration of one time domain sample, and with a maximum expected relative velocity V between the transceivers. Thus, in order to ensure that the out-of-band signal is ydB or less relative to the in-band signal and to be able to avoid using either a clock or a carrier recovery device without substantially affecting the BER we have to:

1. Find the acceptable sampling error $\Delta f'$, relative to one symbol sample, which does not substantially affect the BER. This can be done using the following rules:

$$\text{When } 0.2 \leq \beta \leq 0.3,\ \Delta f' = 7.50\%$$

$$\text{When } 0.3 \leq \beta \leq 0.4,\ \Delta f' = 10.0\%$$

$$\text{When } 0.4 \leq \beta \leq 0.5,\ \Delta f' = 12.5\%$$

$$\text{When } 0.5 \leq \beta \leq 0.6,\ \Delta f' = 15.0\%$$

2. Find Δf such that:

$$V/(\lambda\Delta f)+f_o/\Delta f \leq \Delta f'$$

3. Find K_2 such that

$20\log_{10}|P(f)/P(0)| \leq y$ for $f \geq K_2\sigma f$

4. Find K_1 such that

$2\pi\chi/K_1 < \pi/M$

In this case, we refer to OFDM as Wideband-OFDM. Element 4 is a necessary condition for wideband OFDM, and given a sampling error, the sampling error may be corrected with the methods described in this patent document.

To implement wideband modulation, Orthogonal Frequency Division Multiplexing (OFDM) is preferred in which the information, for example encoded speech, is multiplexed over a number of contiguous frequency bands. Wideband OFDM forces the channel to be frequency selective and causes two types of linear distortion: amplitude distortion and phase distortion. To reduce the effect of amplitude distortion the modulation is preferably phase modulation, while the effect of phase distortion is reduced by employing differential phase modulation. Hence the modulation may be referred to as Differential OFDM (DOFDM). Unlike in other proposed schemes, neither pilot tones nor diversity are required in DOFDM. Possibly, quadrature amplitude modulation might be used, but amplitude modulation makes it difficult to equalize the distorting effects of the channel on the signal.

To implement wideband modulation in a cellular system with a plurality of portables and one or more base stations, a 100 MHz band is divided into 4096 points, as shown in FIG. 2, plus two tail slots of 195.3 KHz each. The 4096 points represent N voice channels (vc). Adjacent points are separated by 24.414 KHz and each point represents a Differential eight Phase Shift Keying (D8PSK) Symbol $e^{j\zeta(n)}$, where $\zeta(n)=\zeta(n-1)+\phi(n)+\chi(n)$. $\phi(n)$ takes one of the eight values $\{0, 2\pi/8, 4\pi/8, \ldots, 14\pi/8\}$ with equal probability for $n=1, 2, \ldots, 4096$ and $\phi(0)$ takes an arbitrary value $X(n)$ also takes an arbitrary value. $\chi(n)$ may be used as a security key and will be known only to the transmitter and receiver. Information in the form of output bits from a vocoder are mapped onto $\phi(n)$. Vocoders are well known in the art and do not need to be described in detail here. The focus here is to transmit the bits with an acceptable Bit Error Rate, i.e. with a BER $\leq 10^{-2}$ for voice and $\leq 10^{-8}$ for data.

Ideally, 40.96 μs (=1/24.414 KHz) is the minimum duration required for one frame to be transmitted without frequency domain intersymbol interference. This can be achieved using a Raised Cosine (RC) pulse with zero roll-off, as shown in FIG. 3a. FIG. 3a illustrates a rectangular (time domain) window corresponding to the RC (frequency domain) pulse. Such a pulse, however, requires an infinite frequency band. To alleviate such a requirement, an RC pulse with a 20% roll-off (i.e. $\beta=0.2$) may be used as shown in FIG. 3b. The frame duration has increased by 20% to 49.152 μs. The two tail slots of 195.3 KHz each (i.e. 8 points each) ensure that the signal outside the entire band of 100.39 MHz is below -50 dB. To allow the frame to spread over the time as a consequence of the multipath nature of the channel, an excess frame duration of 2.848 μs is provided as shown in FIG. 3c, making the frame duration 52 μs in total.

Since the frame duration is 52 μs, the frame rate is 252 frames per 13.104 ms or equivalently, 126 full duplex frames may be transmitted/received every 13.104 ms. The reason for pre-selecting an interval of 13.104 ms is

to ensure a transmission delay to allow one transceiver to communicate with other transceivers at the same time, but must not be so long that the delay becomes unacceptable to the user. Delays longer than about 40 ms are too great for voice, and it is preferable to be lower. For data, the delay may be longer and still be acceptable.

In the exemplary embodiment described here, three bit rates are considered for the vocoder: 18.77 Kbps, 9.16 Kbps and 6.18 Kbps. Table I displays the structure of a vc slot and the number N of vc for each vocoder rate. The control symbols in each vc slot are required for handoff and power control. FIG. 2 shows that N vc can be transmitted simultaneously. This is known as Frequency Division Multiple Access. FIG. 3c shows that 126 full duplex frames can be transmitted every 13.104 ms in a Time Division Multiple Access fashion (TDMA). The total number of Full Duplex voice channels (FDvc) is therefore 126×N and is shown in Table I.

To ensure that the channel is slowly fading, a Time Division Duplex protocol for exchange of information between the portable and the base station is proposed as illustrated in FIG. 4. The protocol is as follows:

1. The portable transmits a frame 410 over one vc slot. See the discussion in relation to FIG. 5a below.
2. The Base Station (BS) receives the frame 410 from the portable and processes (analyzes) it as shown and discussed in relation to FIG. 5b below.
3. Based on the received signal, the BS predistorts a frame 420 and transmits it to the portable over the same vc slot, 520 μs or some other suitable time interval later in which the channel does not change substantially. The time interval will depend on factors such as the frequency, speed of the transceiver and other environmental factors.
4. The portable receives the frame from the BS. See the discussion in relation to FIG. 5c below.
5. Steps 1 through 4 are repeated, as for example by the transmission of the next frame 430, every 13.104 ms until the call is terminated.

During 520 μs, a portable travelling outdoor at 100 km/hr moves 1.44 cm, which leaves the outdoor channel largely unchanged. Indoors, a portable moving at 2 m/s moves 0.1 cm again leaving the channel unchanged. Assuming that the channel is reciprocal and stationary over 520 μs, a predistorted signal, transmitted by the BS, should reach the portable undistorted.

From FIG. 4, one can see that the portable transmits/receives one FDvc every 13.104 ms, while the BS can transmit/receive up to 21 frames or equivalently up to 21×N FDvc every 13.104 ms. The frames 440 labelled frame 2 . . . frame 21 are frames that may be transmitted to other portables. This implies that while one BS is processing its data over 520 μs, six other BS can communicate to their corresponding portables in a Time Division Multiple Access (TDMA) fashion using the same frequency bands. Also, during the 13.104 ms, or such other preselected time interval that is suitable, the BS may communicate with one or more other portables.

When a portable is stationary during a call, it is possible with high probability to have the transmitted signal centered with several deep (frequency domain) nulls, hence, causing speech degradation. Also, narrowband interference over the vc slot can deteriorate the speech. In order to avoid both situations, the signal is preferably

frequency hopped into a new vc slot within the same (frequency domain) frame. This frequency hopping is ordered by the BS which is constantly monitoring the channel frequency response. Monitoring techniques, as well as frequency hopping, are known in the art, and not described here further. When an unacceptable speech degradation is first noticed by the BS a probation period is initiated and maintained for at least 10 cycles (i.e. 10×13.104 ms) unless speech degradation has ceased. In other words, the probation period is terminated if speech degradation has ceased. Frequency hopping is then ordered at the end of the probation period. The period of 10 cycles is long enough to indicate the portable stationarity and is short enough to allow speech interpolation between unacceptable speech frames, hence maintaining good speech quality. As known in the art, the BS ensures that no collisions take place between hopping portables

Digital Signal Processing

The transmitter/receiver block diagrams corresponding to the protocol in FIG. 4 are shown in FIGS. 5*a*, 5*b* and 5*c*. FIG. 5*a* corresponds to step 1 in the protocol described above. Speech is provided to a vocoder 510 where the speech is digitized and coded to create bits of information. The bits are provided to the modulator 512 which turns them into D8PSK symbols, with three bits per symbol. The D8PSK symbols are then processed in the processor 514 which is described in more detail in FIG. 6*a*. The output from the processor is then filtered in low pass filter 516, upconverted to RF frequencies using local oscillator 518 and transmitted by antenna 520. Figure 5*b* corresponds to steps 2 and 3.

In FIG. 5*b*, the received signal at the base station is filtered in a bandpass filter 522, and down converted by mixing with the output of a local oscillator 524. The average power of the downcoverted signal is monitored by a power controller 525 that adjusts the average power to the specifications required by the sampler 526. The adjusted downconverted bits are then sampled in sampler 526 to produce bits of information. The bits are then processed in the deprocessor 528, described in more detail in FIG. 6*b*. An estimate of the phase differential of the received signal is taken in the channel estimator 530, as described in more detail in relation to FIG. 7*a* and 7*b* below, and the estimated phase differential is supplied to a decoder-demodulator 532 to correct the received bits. The estimated phase differential is also supplied to a pre-distorter 534 in the transmitter. At the transmitter in the Base Station, the same blocks are incorporated as in the portable transmitter except that a pre-distorter is used to alter the phase of the D8PSK symbols to make the channel appear Gaussian (ideal) as opposed to a fading channel. The predistorter 534 receives a signal corresponding to the estimated phase differential of the channel. On the (believed reasonable) assumption that the channel is reciprocal, the signal being transmitted is predistorted with the estimated phase differential so that the received signal at the portable with which the BS is communicating will be corrected for any phase distortion over the channel. The advantage of rendering the channel Gaussian is a large saving in the power required to achieve an acceptable BER. The initial power control 525 also sends a signal to the pre-distorter 534 to adjust the transmitted power to an appropriate signal level for the sampler 526 in the portable's receiver depending on the average power of the received signal. Thus if the average power is too low, the transmitted power is increased and if the average power is too high, the transmitted power is decreased. The power controller 525 may also be used in frequency hopping to monitor the average power of the received frequency and determine when frequency hopping need take place.

FIG. 5*c* corresponds to step 4, and shows the receiver of the portable, which is the same as the receiver in the BS except it does not include an estimator or a power controller. These are not required in the portable on the assumption that the BS will carry out the phase estimation and the power control. However, if desired, the portable may include these functions.

FIGS. 6*a*, 6*b* and 6*c* illustrate the function and structure of the processor and the deprocessor respectively in the transmitter and receiver. Software for modelling the function of the processor in a general purpose computer has been filed with the Patent and Trademark Office as frames 3 to 26 of the microfiche appendix and for modelling the function of the deprocessor has been filed with the Patent and Trademark Office as frames 27-41 of the microfiche appendix

FIG. 6*a* shows that the processor is a DSP implementation of an RC pulse shaping filter with a 20% roll-off, followed by an inverse Fourier transform. The processor first inverse Fourier transforms the 4096 D8PSK modulated symbols output from the modulator. The transformed symbols are then triplicated as a group so that the total number of samples is tripled, with three consecutive groups each consisting of the 4096 transformed symbols. The triplication of the signal is illustrated in FIG. 6*c*, where the symbols are shown as first delayed and added together. Next, as shown in FIGS. 6*a* and 6*c*, the three groups are windowed by a Raised Cosine window with a roll-off of 0.2 centered in the middle of the three groups. In other words, the processor takes D8PSK symbols in, pulse shapes them and inverse Fourier transforms them. On the other hand, the deprocessor undoes what the processor did, i.e. it removes the pulse shaping, then Fourier transforms the received signal to obtain the original D8PSK symbols. The first two blocks in FIG. 6*b* are similar to the second two blocks in FIG. 6*a* except for two differences. The two differences are as follows. In the first block of the deprocessor, the repeated groups of symbols are partially overlapped as shown in FIG. 6*c* on the right hand side. In the second block, a rectangular window is used instead of the Raised Cosine. In the preferred implementation, the blocks are repeated three times but other numbers of repetition may be used.

FIGS. 6*a*, 6*b* and 6*c* show that the DSP blocks used in the processor are identical to the ones used in the deprocessor, except for a small change in the two transforms and a small change in the shapes of the two windows. Thus the same hardware can be used by both the processor and the deprocessor.

FIG. 7*a* shows a block diagram of an example of a preferred channel estimator, and FIG. 7*b* is a flow chart showing the operation of the phase estimator. Each of the steps is carried out in a computing means that may be a special purpose computer or a general purpose computer programmed to carry out the digital signal processing described here, as for example with the software that has been filed with the Patent and Trademark Office as frames 42-55 of the microfiche appendix. Other methods of estimating the channel may be used that obtain an estimate of the channel group delay or

phase differential of the transmitted symbols. However, a preferred implementation is described here.

The first block in FIG. 7*a* estimates the envelope A(n) for n=1, . . . , 4096 of the (frequency domain) samples transmitted over the fading channel as output from the deprocessor. The estimate A'(n) is the square-root of the sum of the squares of the quadrature (Q) and inphase (I) samples output from the deprocessor which may be filtered in accordance with known techniques before or after estimation of the envelope. The second block performs the operation:

$\Delta\ln(A'(t))=(\dot{A}'(t))=(A'(n)-A'(n-1))/A'(n)$, for n=2, . . . , 4096, where A'(n) is the estimate of A(n). The third block performs a Hilbert transform operation $H[\Delta\ln(A'(t))]$ on the result of the second block. $H[\Delta\ln(A'(t))]$ is an estimate of $|\Delta\omega(n)|$ for n=2, . . . , 4096, where $\Delta\omega(n)$ is the phase differential of the transmitted signal (ω is the phase of the signal). The Hilbert transform is preferably carried out by taking the discrete fast Fourier transform of the data record, multiplying the positive frequency spectrum of the transform by $-i$ (square root -1), and the negative frequency spectrum of the transform by i, and taking the inverse discrete fast Fourier transform. The result is a set of symbols representing an estimate of the phase differential of the received signal, as determined from its sampled amplitude envelope.

Instead of a Hilbert transform, a different estimation may be made to estimate the phase differential. In this case, firstly, after the electromagnetic signal has been sampled, a series of data frames of a number of consecutive amplitude samples (A(t)) of the electromagnetic signal are constructed. These data frames are then segmented into segments $[t_1,t_2]$, where the amplitude of the electromagnetic signal is at least a predetermined number of dB less than its running mean, for example, 10dB. The following calculation is then applied to these segments of the amplitude samples:

$$\Delta\omega(t) \approx 1/t_0 \frac{-1}{1+(t'/t_0)^2}$$

where $t'=t-t_{min}$, t_{min} is the time in $[t_1, t_2]$ when A(t) reaches its minimum, t is the time from the beginning of the segment, and t_0 is the time from the instant the amplitude of the electromagnetic signal reaches its minimum during the segment until the amplitude reaches double its minimum during the segment. In other words, the phase differential may be calculated from

$$\Delta\omega(t) \approx -t_0/(t_0^2+t'^2).$$

The polarity of $\Delta\omega(n)$ is extracted using the last block shown in FIG. 7*a*. The estimate so calculated does not provide the sign of the differential. This may be determined by known techniques, for example by adding the phase differential to and subtracting the phase differential from the received phase ($\tan^{-1}$ (Q/I)) and taking the sign to be positive if the addition results in the smaller Euclidean distance to the expected value and negative if the subtraction results in the smaller Euclidean distance to the expected value.

Equivalently, for each sample n, the ideal phase closest to $\omega(n)+\Delta\omega(n)$ is determined and labelled $\omega_+(n)$, and the ideal phase closest to $\omega(n)-\Delta\omega(n)$ is determined and labelled $\omega_-(n)$. The two sums $P=\Sigma|\omega_+(n)-\{\omega(n)+\Delta\omega(n)\}|$ and $N=\Sigma|\omega\{\omega(n)-\Delta\omega(n)\}|$ are calculated. If P<N, then $\omega(n)+\Delta\omega(n)$ is used to correct the signal, and if not then $\omega(n)-\Delta\omega(n)$ is used to correct the signal.

For simplicity of the estimator, the determination of the sign need only be carried out for phase differentials greater than a predetermined threshold. This will be in the vicinity of a fade and may be accomplished by segmenting the data record into a segment in which the phase differential is larger than a selected threshold and setting the remainder of the data record to zero. This computation may be carried out with a simple discrimination circuit or equivalent computing means in the estimator.

The bias $\delta\omega$ of the channel group delay is estimated by averaging $\Delta\omega'(n)$ over n for n=1, . . . , 4096 where $\Delta\omega'(n)$ is the measured value of $\Delta\omega(n)$. The estimates A'(n) and $\Delta\omega'(n)$ are used directly in the predistortion filter in FIG. 5*b*, while the estimates $\Delta\omega(n)$ and $\delta\omega$ of the unbiased channel group delay and of the bias of the channel group delay respectively are used in the demodulator.

The complexity of the processor-deprocessor-channel estimator is displayed in Table II. Complexity is measured in Mega Instructions Per Second (MIPS) where one instruction is defined as one complex addition, one complex multiplication and a storage of one complex number. It does not include overhead.

The complexity of the processor-deprocessor-channel estimator in the BS is computed from the complexity of the Inverse Fast Fourier Transform (IFFT)/Fast Fourier Transform (FFT)/Hilbert Transform. The complexity is 4096×12×4×21/13.104 ms for the BS. For the portable, it is computed from the complexity of the FFT/IFFT per vc: (32×5+64+128+256+512+1024+2048+4096)2/13.104 ms for the portable with a 6.18 Kbps vocoder. Such a complexity assumes that the A/D converter operates at 100 MHz with 12 bit precision. As seen in Table II, the portable has smaller complexity due to the fact that the portable transmits/receives one vc in 13.104 ms and the BS transmits/receives up to 21×N vc in 13.104 ms.

Reducing Analog Complexity

Comparing FIG. 1 (prior art) and FIG. 5, it will be seen that several conventional blocks are not used in the present invention, namely the interleaver-deinterleaver, the Power Amplifier (PA), both the clock and the carrier recovery, both the AGC with its associated Passband hard limiter, as well as the equalizer.

From the BS point of view, the interleaver-deinterleaver is not required since the signal is predistorted before transmission forcing the received samples to be independent. From the portable point of view, the interleaver-deinterleaver is not required as a separate entity from the vocoder due to the fact that the channel is highly frequency selective, hence the interleaving/deinterleaving can be applied implicitly in the vocoder over one vc, without a need for a separate time domain interleaver/deinterleaver. This eliminates excess speech delays associated with interleaving/deinterleaving between frames.

The PA is not required since the cells can have, as shown later, a radius of up to at least 250 m outdoors and 30 m indoors, if the transmitted power is up to 6 dBm. Such a power can be generated by the Local Oscillator (LO) without a need for a PA. It is important to avoid using a PA since DOFDM generates a time

domain signal with non constant envelope. A power efficient class C PA cannot be used without distorting the signal. A class A PA can be used at the expense of power efficiency.

A clock recovery device is not required since a sampling error in the time domain is equivalent to a phase shift in the frequency domain. The phase shift is a linear function of frequency. It contributes to the bias in the channel group delay. Such a bias can be easily estimated and removed as mentioned previously by averaging $\omega'(n)$ over n in the frequency domain. Such an estimate is accurate as long as the sampling error is less than 0.2 μs or equivalently less than 20 samples (since in this case, the corresponding phase shift is less than π), and as long as the number of points in one vc is large enough as it is here.

A carrier recovery device is not required since a carrier offset in the time domain is equivalent to a sampling error in the frequency domain. For the chosen RC pulse, a sampling error of up to 10% of the duration of one pulse is acceptable.

This implies that a frequency offset of up to 2.414 KHz is acceptable regardless whether it is due to carrier offset as low as 1 part in a million, i.e. as low as 1 KHz per 1 GHz. When a carrier frequency higher than 2.414 GHz is required, one can decrease in FIG. 2 the number of points per 100 MHz or one can use an RC pulse with a rolloff larger than 20%.

Neither an AGC nor a Passband hard-limiter are required since the level of the received power may be controlled constantly. This is achieved as follows: The portable transmits a frame. The BS receives the frame and predistorts a frame intended for transmission accordingly, assuming that the channel is reciprocal and stationary over 520 μs. This includes controlling the transmitted power according to the received power. The BS transmits the predistorted frame and simultaneously orders the portable to control its power. The order is conveyed using the control symbol in the vc slot (See table I). The degree of power control may be determined using the power controller 525, and the instruction for the inclusion of a power control symbol in the vc may be sent from the power controller 525 to the predistorter 534.

One advantage of wideband modulation over narrowband modulation is that the wideband signal does not experience short term fading the same way the narrowband one does. The wideband signal is mainly affected by shadowing and other long term effects which vary slowly and are easily monitored from one frame to the other as long as the same vc slot is used by the portable to transmit and receive (i.e. as long as TDD is employed).

Finally, conventional equalization, whether it is linear or nonlinear, is not required simply because there is little or no ISI. Also, from the portable point of view, each received vc is predistorted by the BS. Hence, the channel can be modeled approximately as an ideal memoryless Additive White Noise Gaussian (AWGN) channel, assuming channel reciprocity and stationarity over 520 μs. From the BS point of view, since the received signal is not predistorted by the portable prior transmission, the channel estimator is used to reduce the effect of the channel group delay.

Smaller cells

As mentioned previously, the LO generates a 6 dBm average power, hence the signal power transmitted by the BS over one vc slot is (6 dBm $-10\log_{10}N$ dB) while the signal power transmitted by the portable over one vc slot is 0 dBm. Also, since the noise power over a 100 MHz band is -94 dBm, it is (-94 dBm $-10\log_{10}N$ dB) over one vc. A typical noise figure at the receiver is 7 dB. The penalty for not using a matched filter in the receiver is 1 dB. Combining together the above figures provides the portable with an (92 dB $-$ path loss in dB) received signal to noise ratio (SNR), while it provides the BS with an (86 dB $+10\log_{10}N$ dB $-$ path loss in dB) received SNR.

For a path loss of 75 dB, the radius of the urban cell can be 250 m while it can be 30 m for the indoor cell. Such a path loss provides the portable with a 17 dB received SNR, while it provides the BS with an (11 dB $+$ $10\log_{10}N$ dB) received SNR. From the portable point of view, the channel can be modeled approximately as an ideal AWGN channel, hence the 17 dB received SNR results in a 2×10^{-3} BER. On the other hand, the channel can be pessimistically modeled as a Rayleigh fading channel from the BS point of view. The corresponding BER are displayed in Table III which shows that the achieved BER is $\leqq 4\times10^{-3}$. A BER $\leqq 10^{-2}$ is acceptable for voice.

Cell Pattern Reuse

From Table I, the number of Full Duplex voice channels (FDvc) that can be transmitted/received per frame is 136 over 100 MHz, for a 6.18 Kbps vocoder. If the bandwidth is halved to 50 MHz, the number of FDvc per frame is reduced to 68, the noise floor is reduced by 3 dB and the number of full duplex frames that a BS can transmit/receive is doubled to 42, leaving the frame duration, the number of frames per 13.104 ms and the processor/deprocessor complexity unchanged.

Reducing the available bandwidth directly affects the cell pattern reuse. This can be explained as follows, assuming that we are required to offer a minimum of 136 FDvc per cell, that the vocoder rate is 6.18 Kbps and that the cell radius is fixed at 250 m outdoors and 30 m indoors. For a 100 MHz band, we assign one frame per cell and offer 136 FDvc per cell. In this case, the cell pattern reuse consists of 126 cells as shown in FIG. 8*a* which displays a seven layer structure. For a 50 MHz band, we assign two frames per cell and offer 136 FDvc per cell, hence reducing our cell pattern reuse to a 63 cell pattern as shown in FIG. 8*b* which displays a five layer structure. If the available bandwidth is as low as 5.86 MHz, we have 8 vc per frame. Hence we have to assign 18 frames per cell in order to offer the minimum required number of FDvc per cell. This reduces the cell pattern reuse to as low as a 7 cell pattern as shown in FIG. 8*c* which displays a two layer structure.

In FIGS. 8*a*, *b* and *c*, a shaded area is shown around the center of the pattern, indicating 19, 38 and 126 full duplex frames that the central BS can transmit/receive respectively. Tables IVa, *b* and c show the number of cell layers in each cell pattern reuse, the coverage area in Km^2 of the pattern reuse for both the indoor and the urban environments, as well as the carrier to interference ratio (CIR) in dB, for the 100 MHz, 50 MHz and 5.96 MHz bands, respectively. In all cases, the CIR is large enough to sustain a toll quality speech.

Transmission/Reception Protocol

Since the number of FDvc a portable can transmit/-receive is one, while the number of FDvc a BS can transmit/receive is much larger as shown in Table V for

each of the three vocoder rates, we have chosen the following transmission/reception protocol:

1. The portable transmits a frame over a vc.
2. Seven adjacent BS receive the frame from the portable.
3. One BS transmits to the portable, depending for example on the strength of the received signal by each of the BS.

The control of this protocol may use any of several known techniques. For example, the commonly used technique is to have the portable monitor the channel and determine which of several base stations it is closest to. It can then order the nearest BS to communicate with it. Another technique is to use a master control which receives information about the strength of the signal on the channel used by the portable and controls the BS accordingly. Such techniques in themselves are known and do not form part of the invention.

Such a protocol has several advantages. For instance, the location of the portable can be determined with high accuracy based on the received vc at the seven adjacent BS. Locating the portable can assist in the BS hand-off. A BS hand-off and a portable hand-off do not necessarily occur simultaneously, contrary to other prior art systems. In the present invention, when a portable roams from one cell X to an adjacent cell Y, a new vc is not required immediately. What is required is a BS hand-off, meaning that BS Y (associated with cell Y) must initiate transmission to the portable over the same vc, while the BS X (associated with cell X) must terminate its transmission to the portable.

A BS hand-off occurs without the knowledge of the portable and can occur several times before a portable hand-off is required. A portable hand-off is required only when the CIR is below a certain level. In this case, the Mobile Telephone Switching Office (not shown) calls for a portable hand-off in accordance with known procedures. Reducing the portable hand-off rate reduces the probability of dropped calls. This is because a dropped call occurs either because the portable hand-off is not successful or because there are no available channels in cell Y.

The present invention allows the use of post-detection diversity at the BS, and the use of dynamic channel allocation (DCA).

Dynamic Channel Allocation

DCA is made possible by each BS having capability to transmit/receive more than the number of FDvc allocated to its cell, namely seven times the number of FDvc for a 5.86 MHz band and up to twenty-one times the number of FDvc for a 100 MHz as well as a 50 MHz band. The DCA protocol simply consists of borrowing as many FDvc as needed from the adjacent cells, up to a certain limit. The limit for the case when we employ a 6.18 Kbps vocoder, a 5.86 MHz band and 18 frames per cell is obtained as follows. The cell reuse pattern consists of 7 cells. Each cell is preassigned 144 FDvc. Assuming that at peak hours, 75 FDvc are used on the average and 5 FDvc are reserved at all times, then we are left with 64 idle channels which represent the limit on the number of FDvc one can borrow from the cell.

One should distinguish between the limit on the channels borrowed and the limit on the nonpreassigned channels a BS can use. For instance, if a call originates in cell X and the portable roams into an adjacent cell Y where no preassigned cells are available, BS Y does not need to borrow immediately a new channel from an adjacent cell. It can use the original channel as long as the level of CIR is acceptable. If on the other hand, a portable wants to initiate a call in cell Y where all preassigned channels are used, BS Y can borrow a channel from an adjacent cell up to a limit of 64 channels per cell.

The main advantage of DCA over Fixed Channel Allocation (FCA) is the increase in traffic handling capability For FCA, a 7 cell pattern each with a preassigned 144 Fdvc can carry a total traffic of 880.81 Erlang at 0.01 Blocking Probability (BP). For DCA, a 7 cell pattern consists of 6 cells each with 80 FDvc that can carry a total traffic of 392.17 Erlang, combined with one cell with 528 FDvc that can carry 501.74 Erlang. The total traffic is therefore 893.91 Erlang. This increase appears to be marginal (1.5%). However, if 501.74 Erlang are actually offered to one cell in the FCA system (with 14 FDvc/cell), while the six other cells carry 392.17/6=65.36 Erlang per cell, the BP at that busy cell 0.714 while it is negligible at the six other cells. The total blocked traffic (i.e. lost traffic) in the FCA system is then equal to ($6\times65.36\times0.0+1\times0.714\times501.24$) 358.24 Erlang. This represents a 0.4 average BP. If the DCA is allowed such a loss, its traffic handling capacity would increase to 1768.04 Erlang which represents a 100% increase in traffic handling capacity over the FCA system, or equivalently a 160% increase in the number of available FDvc. The DCA system thus represents a marked improvement over the FCA system.

Voice Activation

Voice activation is controlled by the BS according to techniques known in the art. At any instant during a conversation between a BS and a portable, there are four possibilities:

1. BS talks while the portable listens.
2. BS listens while the portable talks.
3. BS and portable talk simultaneously.
4. BS and portable listen simultaneously.

The BS controls the voice activation procedure by allocating in cases 1, 3 and 4 three slots (frames 1.1, 1.2 and 1.3) to the BS and one slot the portable (frame 1) every four slots as shown in FIG. 9*a*. Likewise up to 21 portables may communicate with the base station in like fashion.

In case 2, on receiving a signal from the portable, the BS allocates three slots (frames 1.1, 1.2 and 1.3) to the portable and one slot (frame 1) to the BS every four slots as shown in FIG. 9*b*. Likewise, up to 21 other portables may communicate with the base station in like fashion. Consequently, instead of transmitting two full duplex voice frames over four slots as in FIG. 4, voice activation allows us to transmit three full duplex voice frames over four slots. Hence, voice activation provides a 50% increase in the number of available FDvc at the expense of increasing DSP complexity.

Capacity

The capacity of Code Division Multiple Access (CDMA) may be defined as the number of half duplex voice channels (HDvc) effectively available over a 1.25 MHz band per cell. Based on such a definition, Table IV displays the capacity of analog FM and of the present system with a 6.18 Kbps vocoder, 5.86 MHz band, 1 frame per cell and DCA. As shown in Table IV, the capacity of analog FM is 6 HDvc/1.25 MHz/cell while for the present system it is 150 HDvc/1.25 MHz/cell.

The 6.25 MHz band consists of 5.86 MHz plus two tail slots When voice activation is used, the capacity of the present system is increased by 1.5 times to 225 HDvc/1.25 MHz/cell, a 38 fold increase over analog FM.

Local Area Networks

The invention may also be applied to produce a 48 Mbps wireless LAN, which also satisfies the technical requirements for spread spectrum.

For wireless LAN, wideband differential orthogonal frequency division multiplexing is again employed. The LAN will incorporate a plurality of transceivers, all more or less equal in terms of processing complexity, and possibly with identical components except for addresses.

To implement wideband modulation for a LAN, a 26 MHz band is divided into 128 points, as shown in FIG. 10, plus two tail slots of 1.48 MHz each within the 26 MHz band. Adjacent points are separated by 180 KHz and each point, as with the application described above for a portable-base station, represents a D8PSK symbol. The transmitter components will be the same as shown in FIG. 5*b*, with suitable modifications as described in the following, and will include an encoder. The output bits from the encoder are mapped onto the D8PSK symbols.

The frame duration for the symbols is illustrated in FIG. 11 A rectangular time domain window corresponding to a RC frequency domain pulse has a 5.55 μs duration, and includes a 25% roll-off and excess frame duration of 0.26 μs, making a total 7.2 μs duration for the frame.

For such a wireless local area network (LAN), in which the transceivers are equal, the Time Division Duplex protocol is as illustrated in FIG. 12 (assuming there are at least a pair of transceivers):

1. A first transceiver transmits a signal (frame 0) over the entire frame.
2. A second transceiver receives the signal from the first transceiver and processes (analyzes) it.
3. Based on the received signal, the second transceiver predistorts and transmits nine frames (frames 1-9) to the first transceiver immediately.

Each transceiver has transmitter components similar to those illustrated in FIG. 5*b*, with suitable modifications to the internal structure to allow the use of the particular frequency band and frame duration employed.

The transmitter/receiver functional and structural block diagrams are shown in FIGS. 13*a*, 13*b* and 13*c* for the exchange of data. Data is provided to an encoder 810 where the data is digitized and coded to create bits of information. The bits are provided to the modulator 812 which turns them into D8PSK symbols, with three bits per symbol. The D8PSK symbols are then processed in the processor 814 which is described in more detail in FIG. 14*a* The output from the processor is then filtered in low pass filter 816, upconverted to RF frequencies using local oscillator 818 and transmitted by antenna 820.

In FIG. 13*b*, the received signal at the base station is filtered in a bandpass filter 822, and down converted by mixing with the output of a local oscillator 824. The average power of the downcoverted signal is monitored by an initial power control 825 that adjusts the average power to the specifications required by the sampler 826. The adjusted downconverted signal is then sampled in sampler 826 to produce bits of information. The bits are then processed in the deprocessor 828, described in more detail in FIG. 14*b*. An estimate of the phase differential is taken in the channel estimator 830, as described in more detail in relation to FIG. 7 above, and the estimated phase differential is supplied to a decoder/-demodulator 832 to correct the received bits. The estimated phase differential is also supplied to a pre-distorter 834 in the transmitter. At the transmitter in the Base Station, the same blocks are incorporated as in the portable transmitter except that a pre-distorter is used to alter the envelope and phase of the D8PSK symbols to make the channel appear Gaussian (ideal) as opposed to a fading channel. The initial power control 825 also sends a signal to the pre-distorter 834 to adjust the transmitted power to an appropriate signal level for the sampler 826 in the first transceiver. It will be appreciated that a pre-distorter will be included in the first transceiver's transmitter but that it will not be operable, except when the first transceiver is operating as a base station.

FIG. 13*c* shows the functional blocks of the receiver of the first transceiver, which is the same as the receiver in the second transceiver except it does not include an estimator. The processor is illustrated in FIG. 14*a* and 14*c* and the deprocessor in FIG. 14*b* and 14*c*. The processor first inverse Fourier transforms the 128 D8PSK symbols output from the modulator The transformed symbols are then triplicated as a group so that the total number of samples is tripled (see the left side of FIG. 4*c*), with three consecutive groups each consisting of the 128 transformed symbols. Next, the three groups are windowed by a Raised Cosine window with a roll-off of 0.25 centered in the middle of the three groups. In other words, the processor takes D8PSK symbols in, pulse shapes them and inverse Fourier transforms them. On the other hand, the deprocessor undoes what the processor did, i.e. it removes the pulse shaping, then Fourier transforms the received signal to obtain the original D8PSK symbols The first two blocks in FIG. 14*b* are similar to the second two blocks in FIG. 14*a* except for two differences as follows. In the first block shown in FIG. 14*b*, the repeated groups of symbols are partially overlapped, as shown in FIG. 14*c*. In the second block, a rectangular window is used instead of the Raised Cosine to produce 128 output samples corresponding to the 416 input samples.

The phase estimator is the same as that shown in FIG. 7, except that there are only 128 input samples, and the same description applies.

For both the LAN and cellular networks, the present system is designed to operate as a spread spectrum system preferably over such bands as are permitted, which at present are the 902–928 MHz band, 2.4–2.4835 GHz and 5.725–5.85 MHz. The carrier frequency in the local oscillator shown in FIGS. 5*a*, *b* and *c* will then be 915 MHz in the case of the 902–928 MHz band, and the frequencies used for modulation will be centered on this carrier frequency.

Alternative Embodiments

A person skilled in the art could make immaterial modifications to the invention described and claimed in this patent without departing from the essence of the invention.

For example, a system may consist of one or more central controllers (comparable to the Base Stations in the exemplary cellular system described) and some

slave units (comparable to the portables). The slave unit executes the commands it receives from the central controller. The commands may be requesting the slave unit to transmit a receive acknowledge, a status code or information that the slave has access to. The command may also be to relay the command or the information to another slave unit.

We claim:

1. A transceiver including a transmitter for transmitting electromagnetic signals and a receiver for receiving electromagnetic signals having amplitude and phase differential characteristics, the transmitter comprising:

an encoder for encoding information;

a wideband frequency division multiplexer or multiplexing the information onto wideband frequency channels;

a low pass filter;

a local oscillator for upconverting the multiplexed information for transmission;

a processor for applying a fourier transform to the multiplexed information to bring the information into the time domain for transmission;

further including, in the receiver of the transceiver;

a bandpass filter for filtering the received electromagnetic signals;

a local oscillator for downconverting the received electromagnetic signals to produce output;

a sampler for sampling the output of the local oscillator to produce sampled signals to the channel estimator;

a channel estimator for estimating one or both of the amplitude and the phase differential of the received signals to produce as output one or both of an estimated amplitude and an estimated phase differential respectively; and

a decoder for producing signals from the sampled signals and the output from the channel estimator.

2. The transceiver of claim 1 further including, in the receiver of the transceiver:

a deprocessor for applying an inverse Fourier transform to the samples output from the sampler.

3. The transceiver of claim 2 further including, in the receiver of the transceiver:

a power controller before the sampler for monitoring the power of the received signal and for controlling the power of the signal.

4. The transceiver of claim 3 further including, in the transmitter of the transceiver:

a pre-distorter before the processor, the pre-distorter being connected to the channel estimator, for pre-distorting a signal to be transmitted with one or both of the estimated amplitude or the estimated phase differential.

5. The transceiver of claim 4 in which the power controller is also connected to the pre-distorter for controlling the power of the signal to be transmitted.

6. The transceiver of claim 1 further including: means to modify the received signal with one or both of the estimated amplitude and phase differential respectively.

7. A method for allowing a number of wireless transceiver to exchange frames of information, the method comprising the steps of:

multiplexing a first frame of information over a number of frequencies within a frequency band at a first transceiver to produce multiplexed information;

processing the multiplexed information at the first transceiver,

transmitting the processed information to a second transceiver using a carrier frequency fc;

receiving the processed information at the second transceiver; and

processing the processed information at the second transceiver during a first time interval;

in which the frequency band is formed from a first set of K1 points and a pair of tall slots each having K2 points, each of the points being separated by a frequency range of Δf, the second transceiver has a maximum expected clock error χT, where T is the duration of one time domain sample, the information is multiplexed over a number M of levels, and K1 selected such that $2\pi\chi/K1<\pi/M$, whereby the width of the frequency band is chosen so that neither carrier nor clock recovery is required at the second transceiver.

8. The method claim 7 further including transmitting a second frame of information from the second transceiver to the first transceiver within the same frequency band.

9. The method of claim 7 in which K2 is selected so that the out of band signal is less than a given level.

10. The method of claim 7 in which the first and second transceivers have an expected maximum relative velocity V, the first and second transceivers have carrier frequencies with a frequency offset from each other of of the carrier frequency has a corresponding travelling wavelength λ and Δf is selected so that $[V/(\lambda\Delta f)+of/\Delta f]$ is less than or equal to a preselected sampling error.

11. The method of claim 7 in which processing the multiplexed information at the second transceiver further includes calculating the mean of the phase shift due to sampling error by summing an estimated phase differential of the received signal.

12 The method of claim 11 in which the mean of the phase shift due to sampling error is divided by K1 and the result removed from the phase differential of the received signal.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,282,222 Page 1 of 1
DATED : January 25, 1994
INVENTOR(S) : M. Fattouche et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 19,
Line 14, "or" should read -- for --
Line 21, "fourier" should read -- Fourier --
Line 24, "transceiver;" should read -- transceiver: --

Column 20,
Line 8, "transceiver" should read -- transceivers --
Line 14, "transceiver," should read -- transceiver; --
Line 22, "tall slots" should read -- tail slots --
Line 42, "of of' the" should read -- of fo, the --
Line 44, "+of/Δf]" should read -- +fo/Δf] --

Signed and Sealed this

Eighteenth Day of September, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer *Acting Director of the United States Patent and Trademark Office*

EXHIBIT B

US00RE37802E

(19) **United States**
(12) **Reissued Patent**
Fattouche et al.

(10) **Patent Number: US RE37,802 E**
(45) **Date of Reissued Patent: Jul. 23, 2002**

(54) **MULTICODE DIRECT SEQUENCE SPREAD SPECTRUM**

(75) Inventors: **Michel T. Fattouche; Hatim Zaghloul**, both of Calgary (CA)

(73) Assignee: **Wi-LAN Inc.**, Calgary (CA)

(21) Appl. No.: **09/151,604**

(22) Filed: **Sep. 10, 1998**

Related U.S. Patent Documents

Reissue of:
(64) Patent No.: **5,555,268**
Issued: **Sep. 10, 1996**
Appl. No.: **08/186,784**
Filed: **Jan. 24, 1994**

(51) **Int. Cl.**^{7} **H04B 1/707**; H04B 1/69
(52) **U.S. Cl.** 375/141; 370/209; 375/146; 375/147; 380/34
(58) **Field of Search** 375/200, 201, 375/202, 203, 204, 206, 207, 208, 209, 210, 130–153, 271, 279, 280, 322, 329, 332; 380/34, 46; 370/203, 204, 205, 206, 207, 208, 209, 210, 211; 364/717.01, 717.02, 717.03, 717.04, 717.05, 717.06, 717.07; 331/78; 714/746, 752, 778, 781, 782

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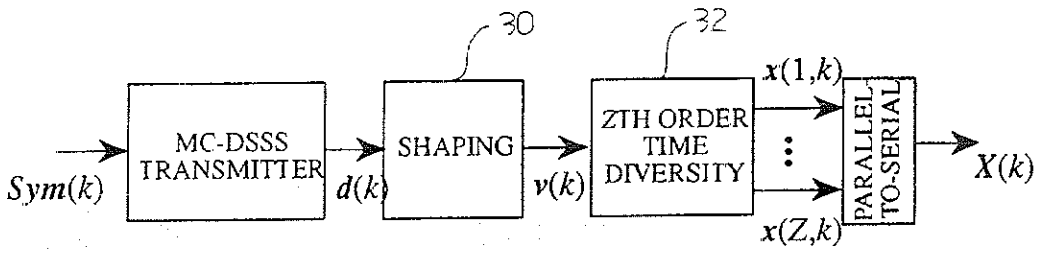
Primary Examiner—Bernarr E. Gregory
(74) *Attorney, Agent, or Firm*—Christensen O'Connor Johnson Kindness PLLC

(57) **ABSTRACT**

In this patent, we present MultiCode Direct Sequence Spread Spectrum (MC-DSSS) which is a modulation scheme that assigns up to N DSSS codes to an individual user where N is the number of chips per DSSS code. When viewed as DSSS, MC-DSSS requires up to N correlators (or equivalently up to N Matched Filters) at the receiver with a complexity of the order of N^2 operations. In addition, a non ideal communication channel can cause InterCode Interference (ICI), i.e., interference between the N DSSS codes. In this patent, we introduce new DSSS codes, which we refer to as the "MC" codes. Such codes allow the information in a MC-DSSS signal to be decoded in a sequence of low complexity parallel operations which reduce the ICI. In addition to low complexity decoding and reduced ICI MC-DSSS using the MC codes has the following advantages: (1) it does not require the stringent synchronization DSSS requires, (2) it does not require the stringent carrier recovery DSSS requires and (3) it is spectrally efficient.

40 Claims, 20 Drawing Sheets



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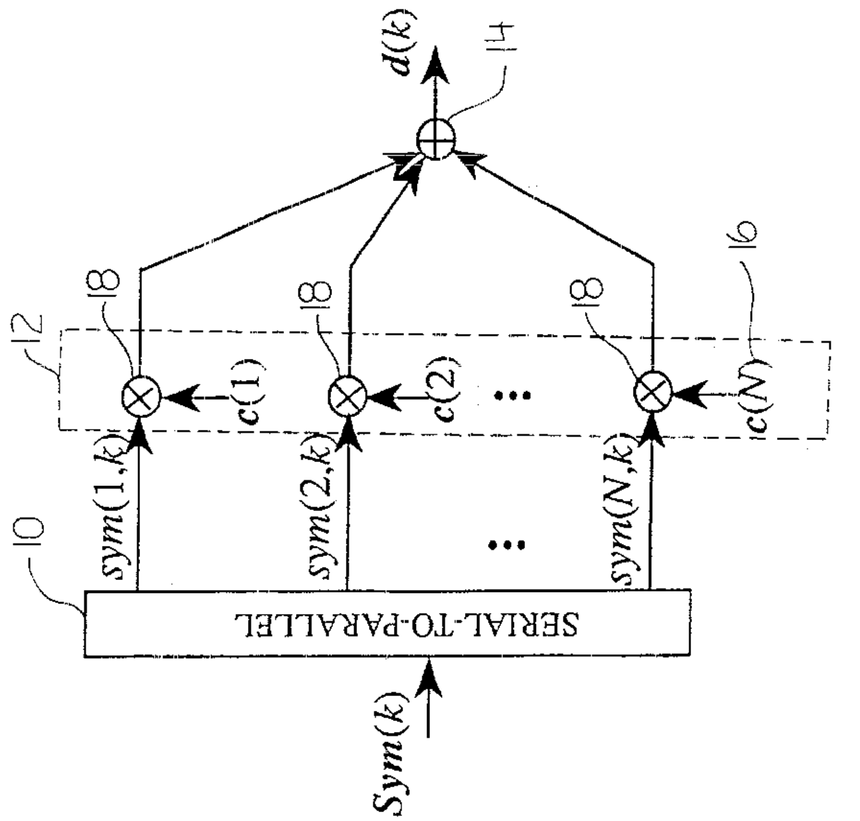

d(k)
14
18
18
18
16
12
c(1)
c(2)
c(N)
sym(1,k)
sym(2,k)
sym(N,k)
10
SERIAL-TO-PARALLEL
Sym(k)

FIGURE 1

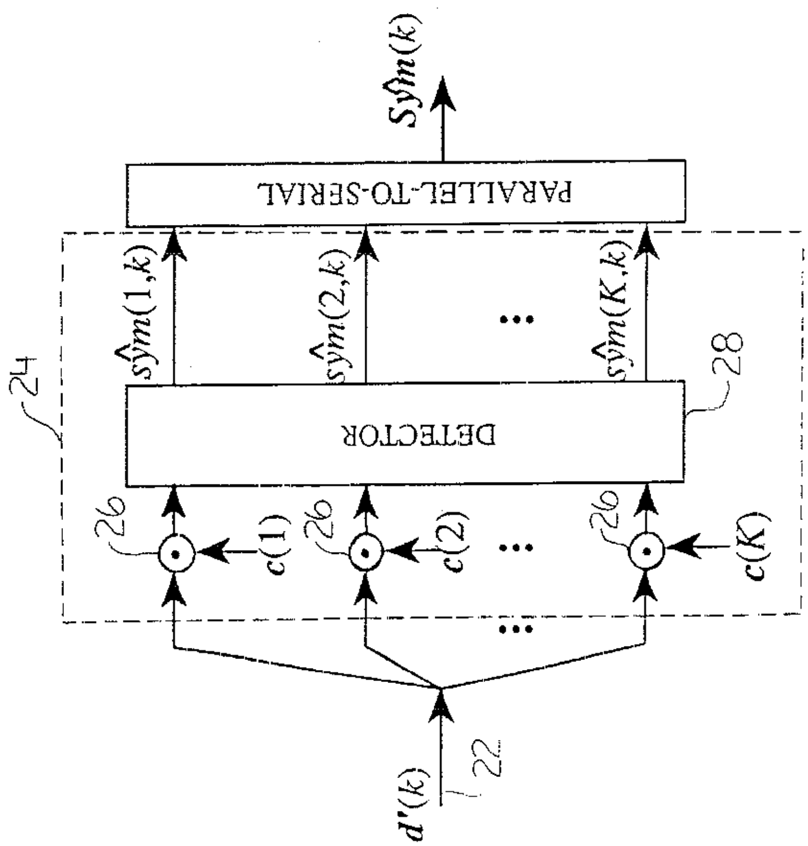


FIGURE 2

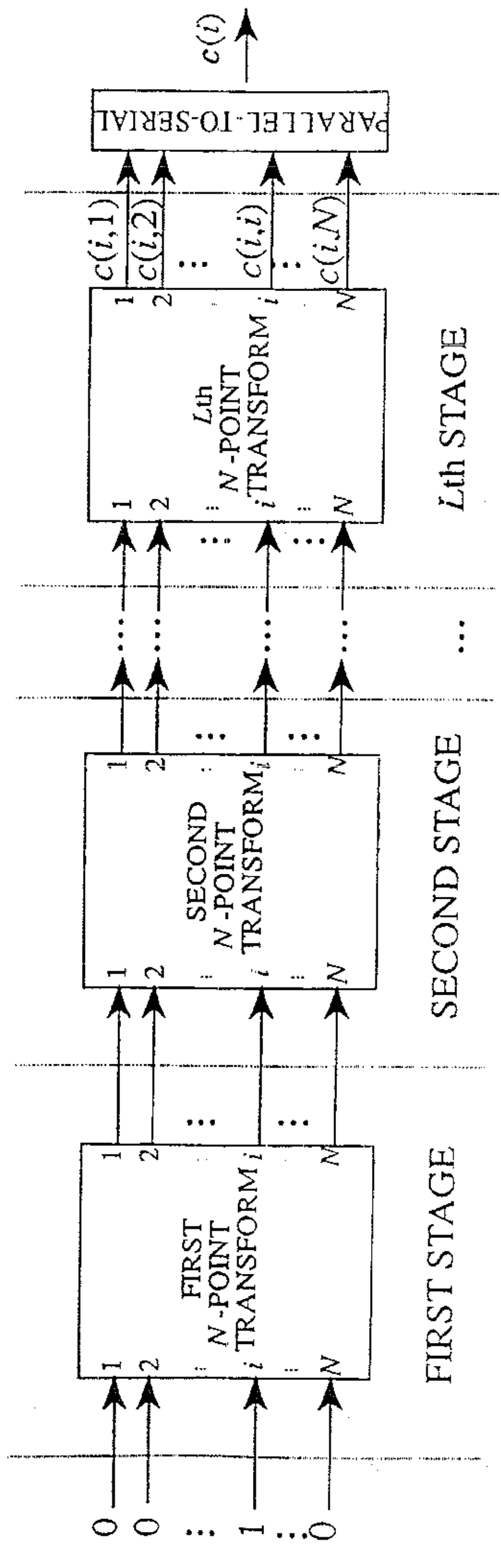
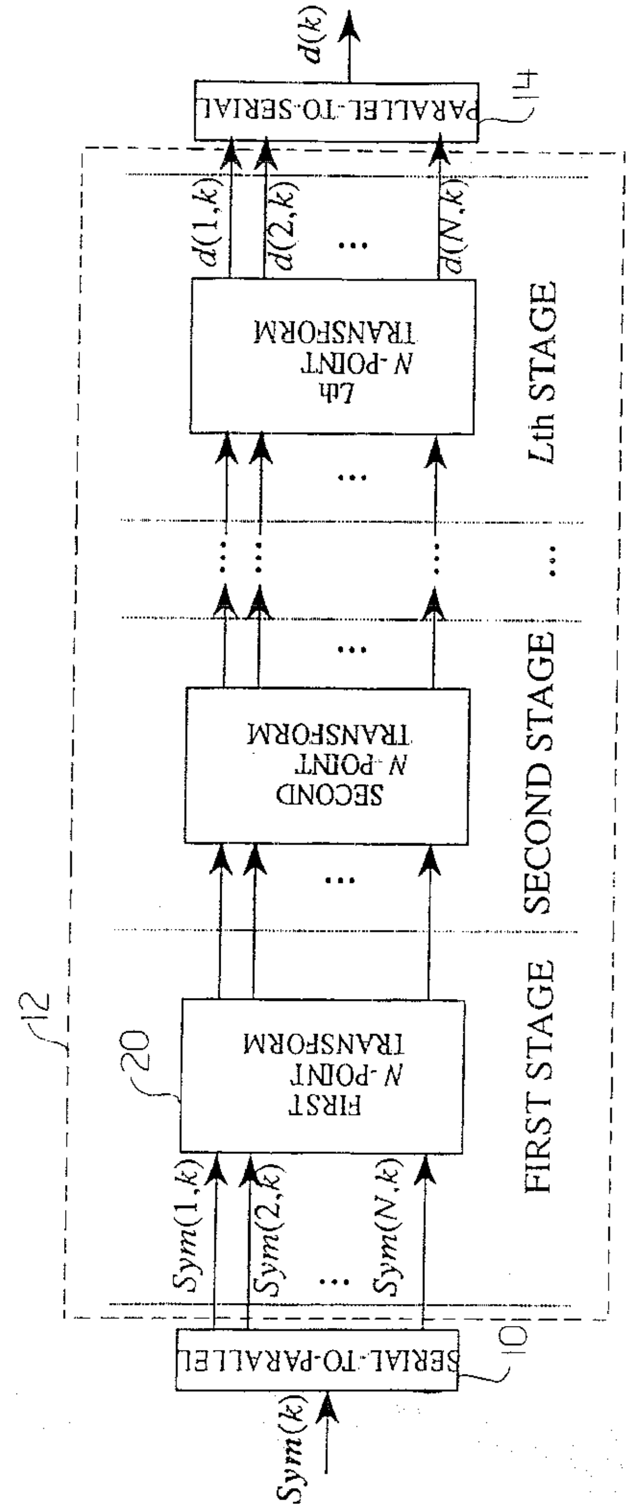
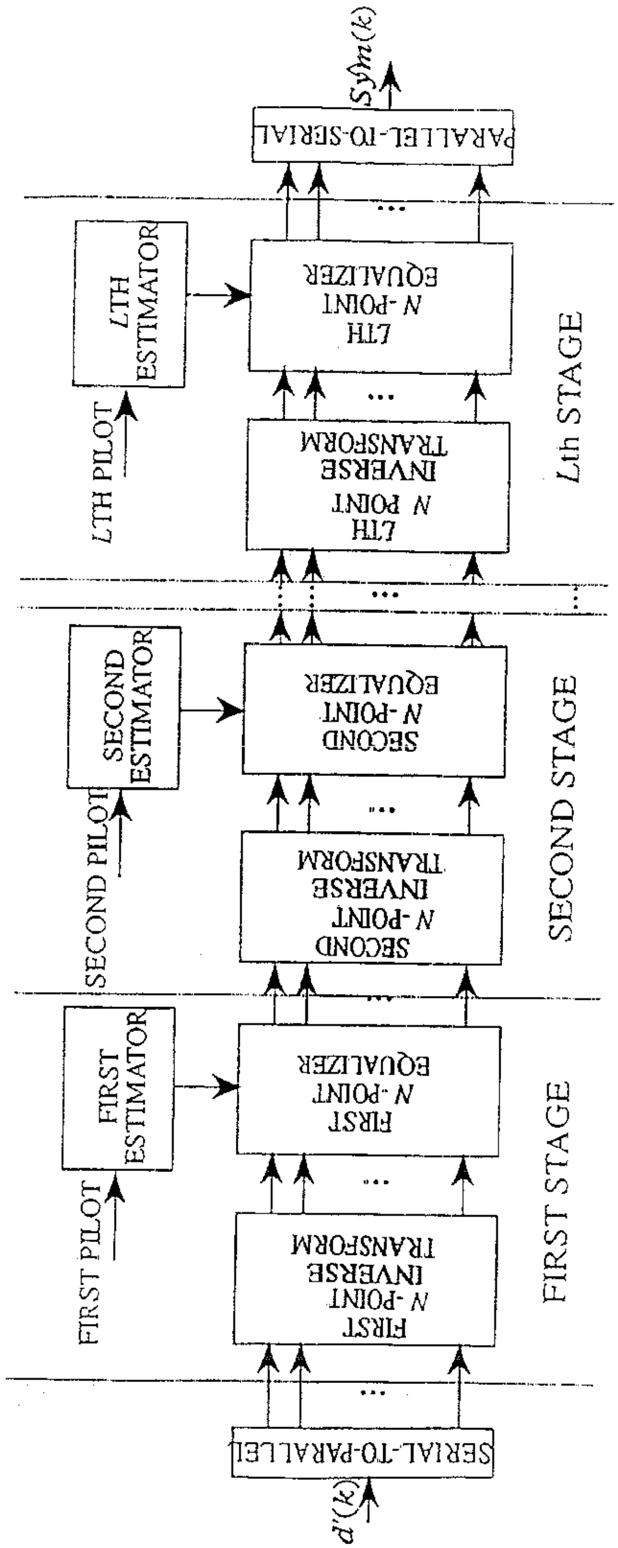

0 0 ... 1 ... 0
FIRST N-POINT TRANSFORM
FIRST STAGE
SECOND N-POINT TRANSFORM
SECOND STAGE
Lth N-POINT TRANSFORM
Lth STAGE
c(i,1)
c(i,2)
c(i,i)
c(i,N)
PARALLEL-TO-SERIAL
c(i)

FIGURE 3



d(k)
PARALLEL-TO-SERIAL
14
d(1,k)
d(2,k)
d(N,k)
Lth N-POINT TRANSFORM
Lth STAGE
SECOND N-POINT TRANSFORM
SECOND STAGE
FIRST N-POINT TRANSFORM
FIRST STAGE
12
20
Sym(1,k)
Sym(2,k)
Sym(N,k)
SERIAL-TO-PARALLEL
10
Sym(k)

FIGURE 4



$d'(k)$
SERIAL-TO-PARALLEL
FIRST N-POINT INVERSE TRANSFORM
FIRST N-POINT EQUALIZER
FIRST ESTIMATOR
FIRST PILOT
FIRST STAGE
SECOND N-POINT INVERSE TRANSFORM
SECOND N-POINT EQUALIZER
SECOND ESTIMATOR
SECOND PILOT
SECOND STAGE
LTH N POINT INVERSE TRANSFORM
LTH N-POINT EQUALIZER
LTH ESTIMATOR
LTH PILOT
Lth STAGE
PARALLEL-TO-SERIAL
$Sym(k)$

FIGURE 5

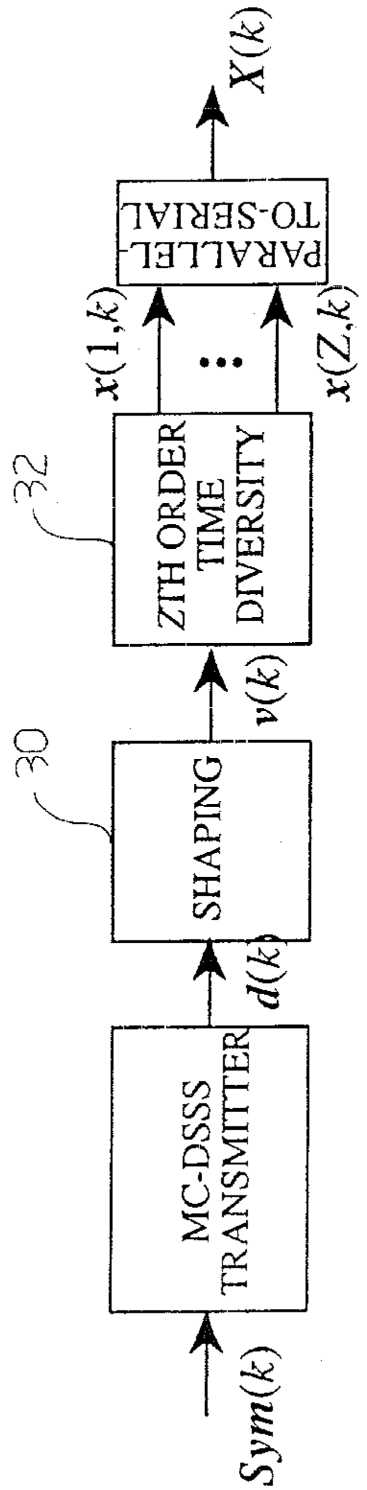

Sym(k)
MC-DSSS TRANSMITTER
d(k)
SHAPING
30
v(k)
ZTH ORDER TIME DIVERSITY
32
x(1,k)
x(Z,k)
PARALLEL-TO-SERIAL
X(k)

FIGURE 6

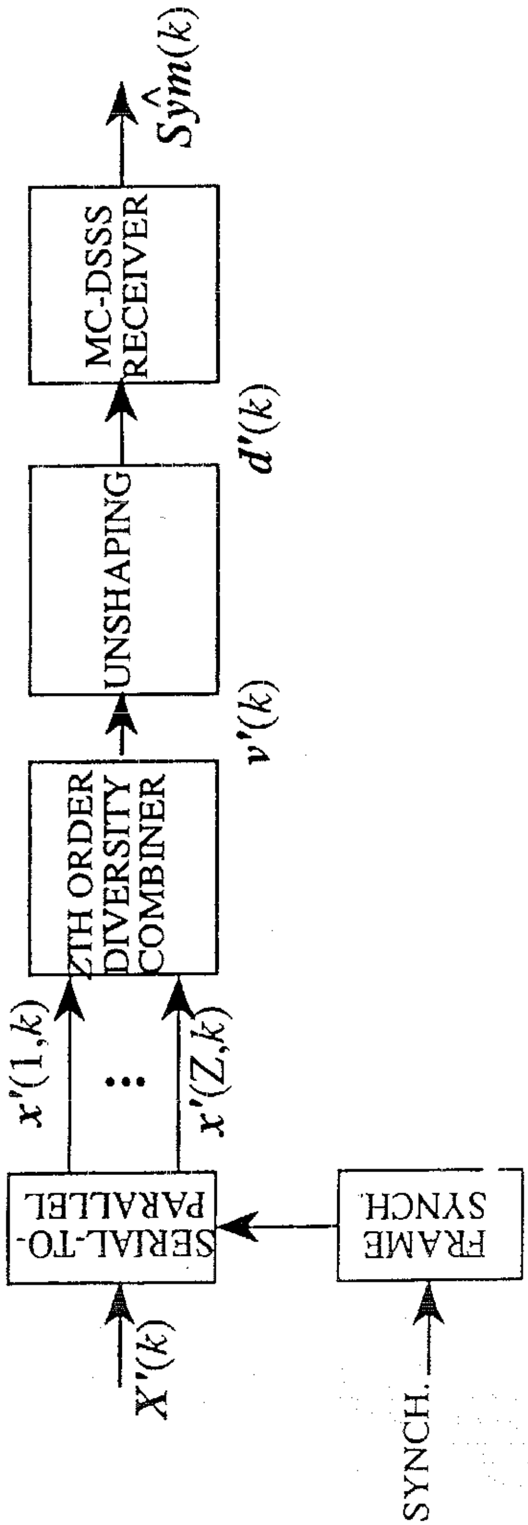

SYNCH.
FRAME SYNCH
X'(k)
SERIAL-TO-PARALLEL
x'(1,k)
x'(Z,k)
ZTH ORDER DIVERSITY COMBINER
v'(k)
UNSHAPING
d'(k)
MC-DSSS RECEIVER
$\hat{Sym}(k)$

FIGURE 7

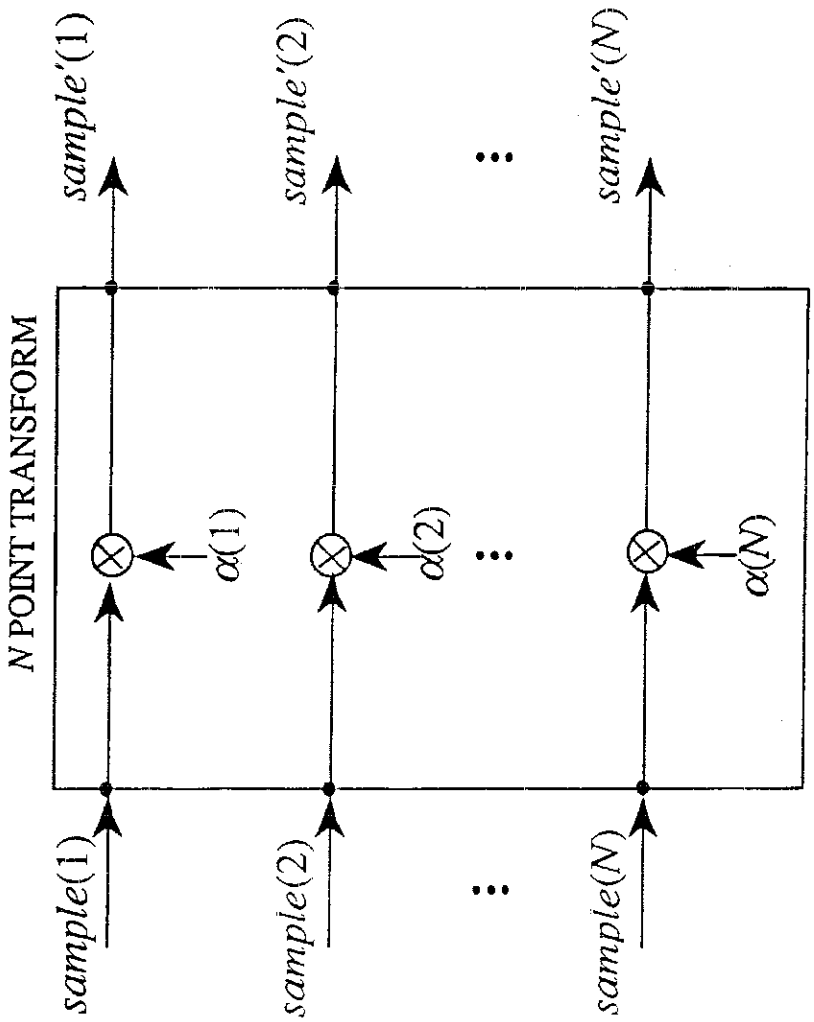

N POINT TRANSFORM
sample(1)
sample(2)
sample(N)
α(1)
α(2)
α(N)
sample'(1)
sample'(2)
sample'(N)

FIGURE 8

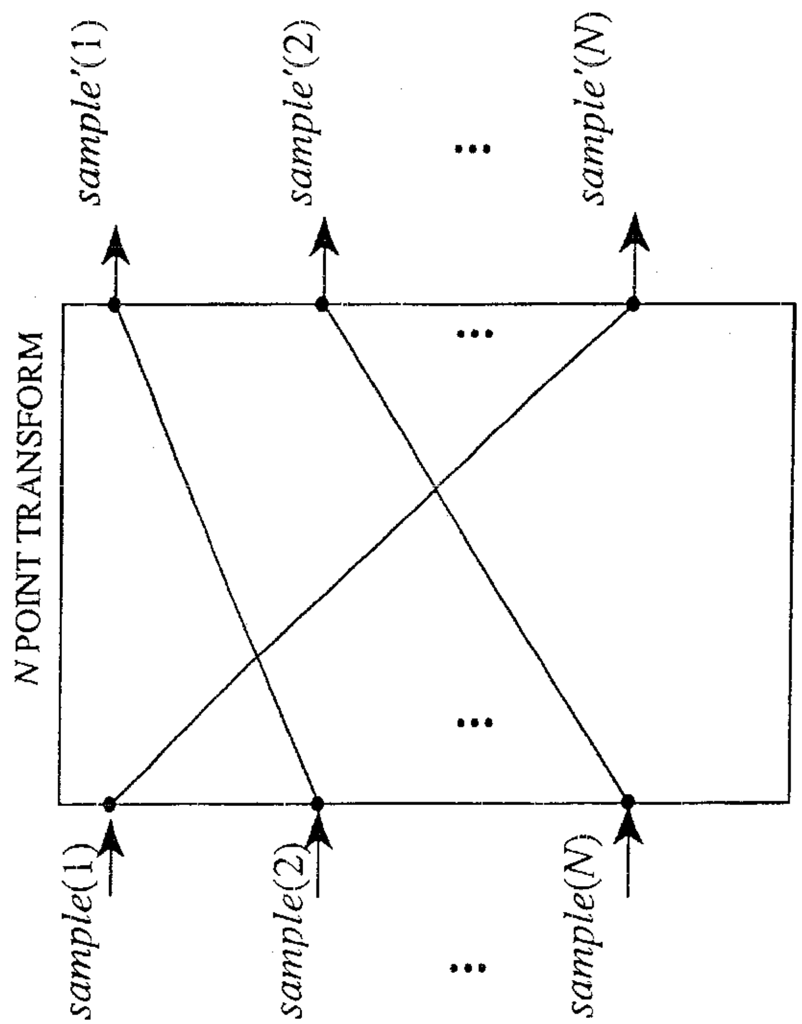

N POINT TRANSFORM
sample(1)
sample(2)
...
sample(N)
sample'(1)
sample'(2)
...
sample'(N)

FIGURE 9

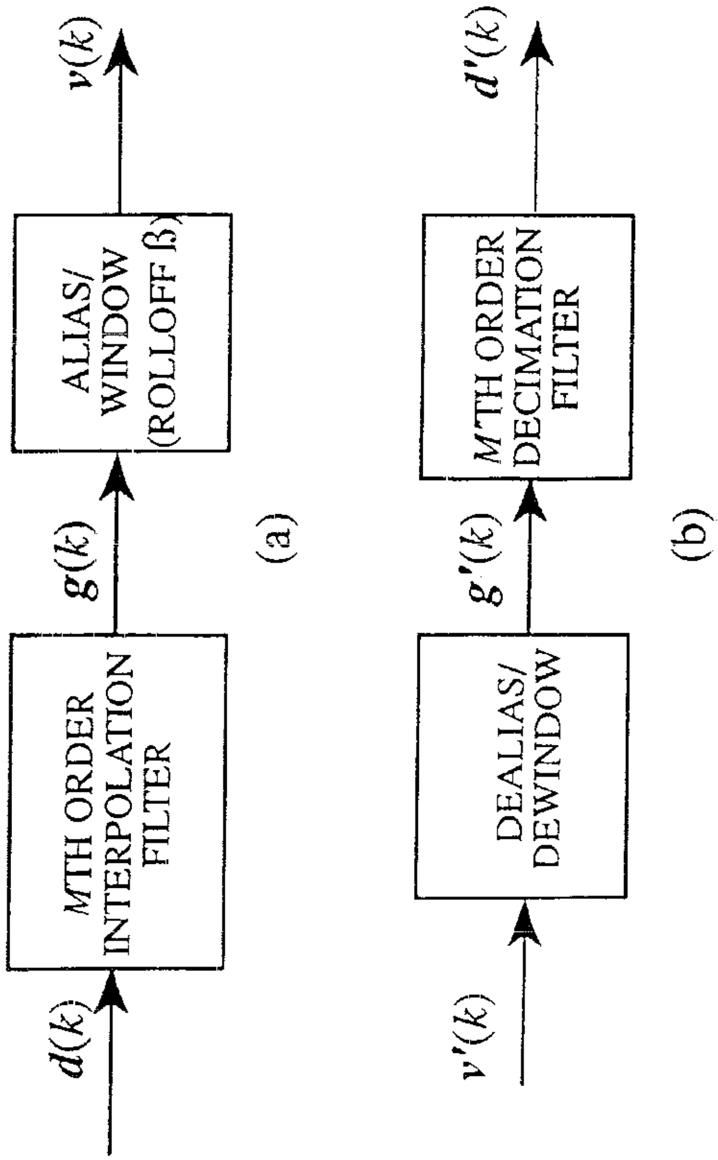

d(k)
MTH ORDER INTERPOLATION FILTER
g(k)
ALIAS/ WINDOW (ROLLOFF ß)
v(k)
(a)
v'(k)
DEALIAS/ DEWINDOW
g'(k)
MTH ORDER DECIMATION FILTER
d'(k)
(b)

FIGURE 10

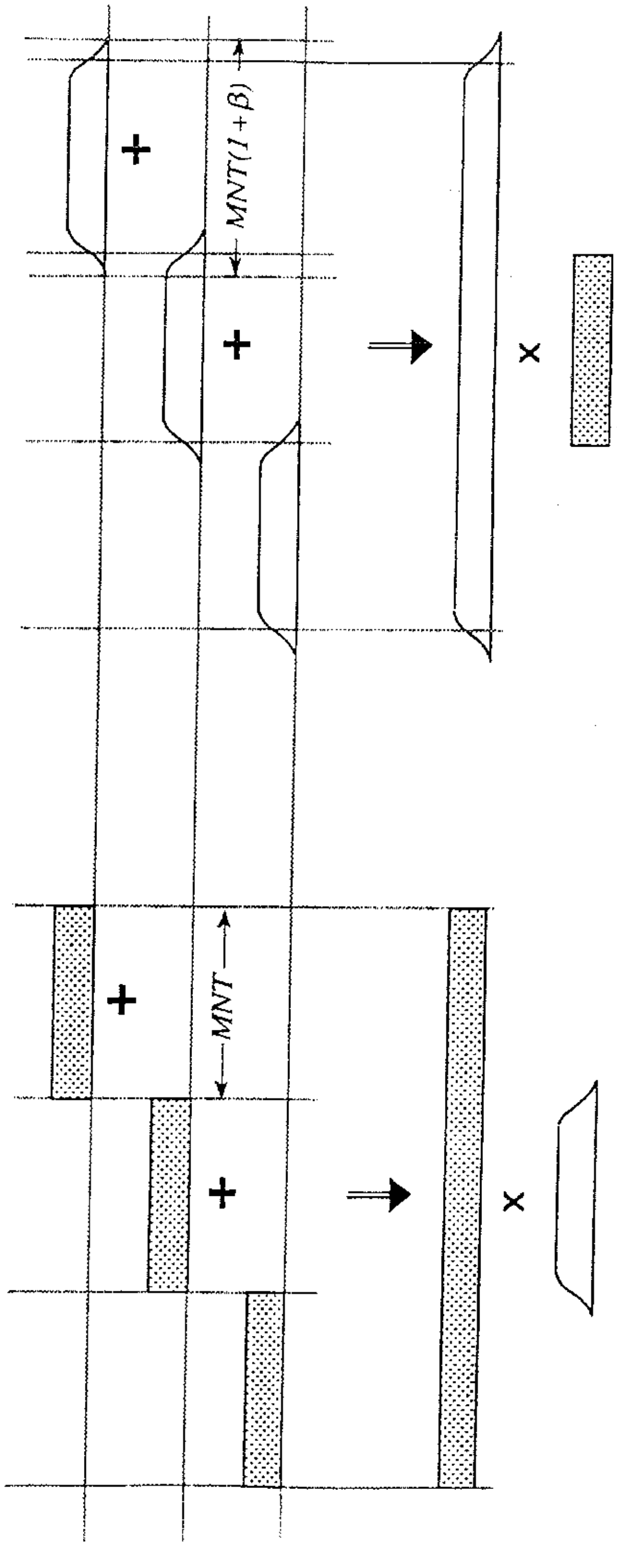


FIGURE 11

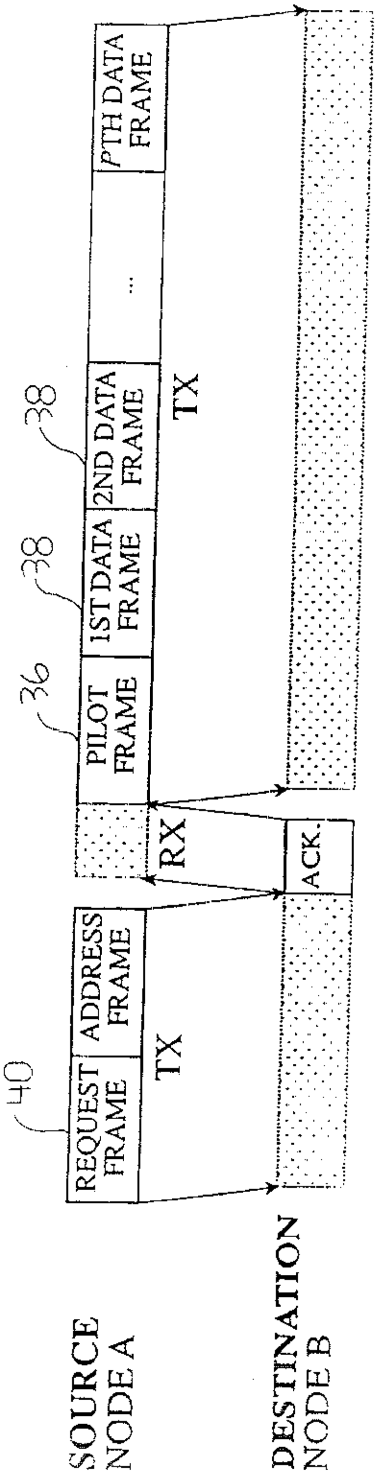

SOURCE NODE A
DESTINATION NODE B
REQUEST FRAME
ADDRESS FRAME
TX
RX
ACK.
PILOT FRAME
1ST DATA FRAME
2ND DATA FRAME
...
PTH DATA FRAME
TX

FIGURE 12

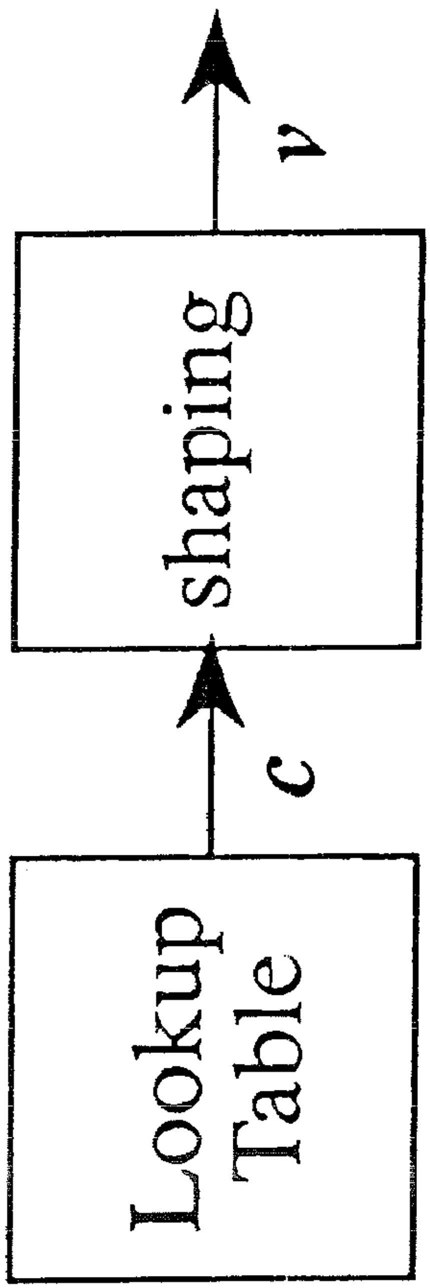
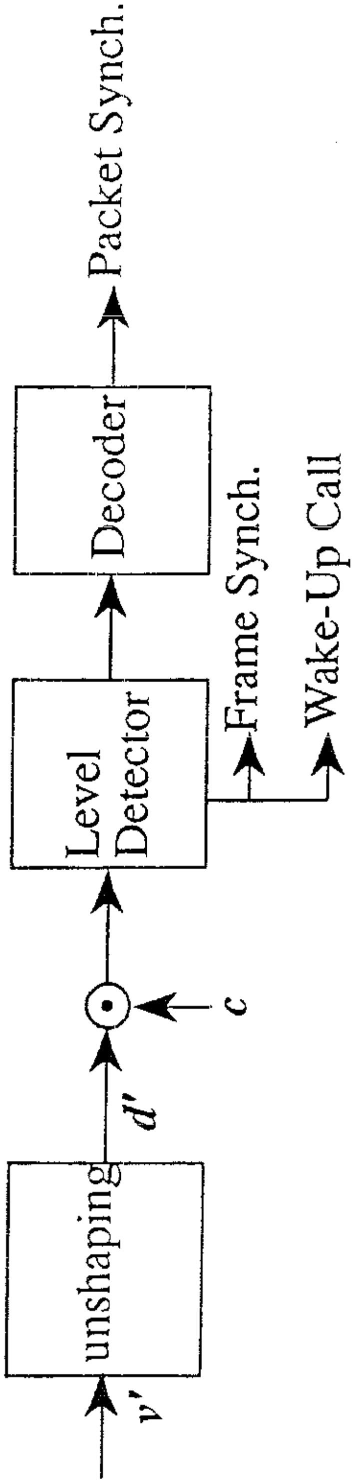
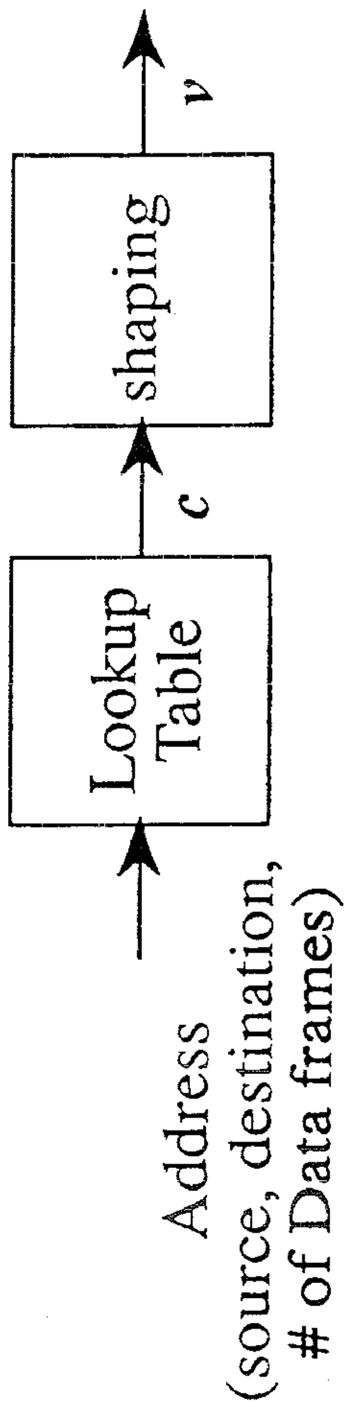


FIGURE 13



v'
unshaping
d'
c
Level Detector
Frame Synch.
Wake-Up Call
Decoder
Packet Synch.

FIGURE 14



Address
(source, destination,
# of Data frames)
Lookup
Table
c
shaping
v

FIGURE 15

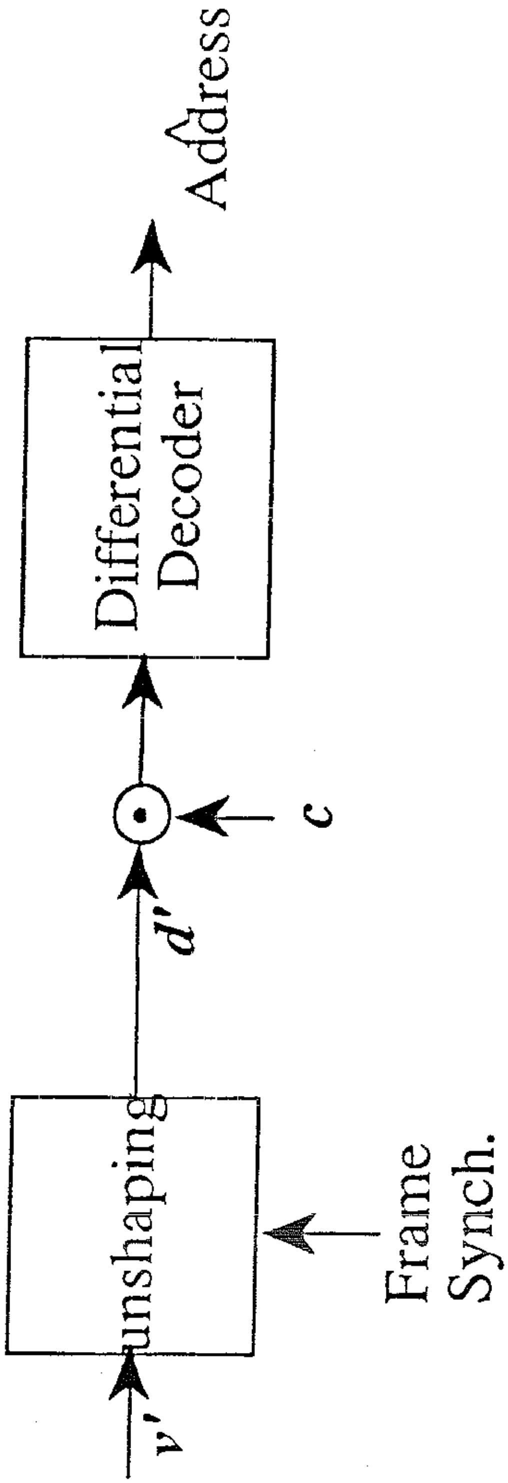


FIGURE 16

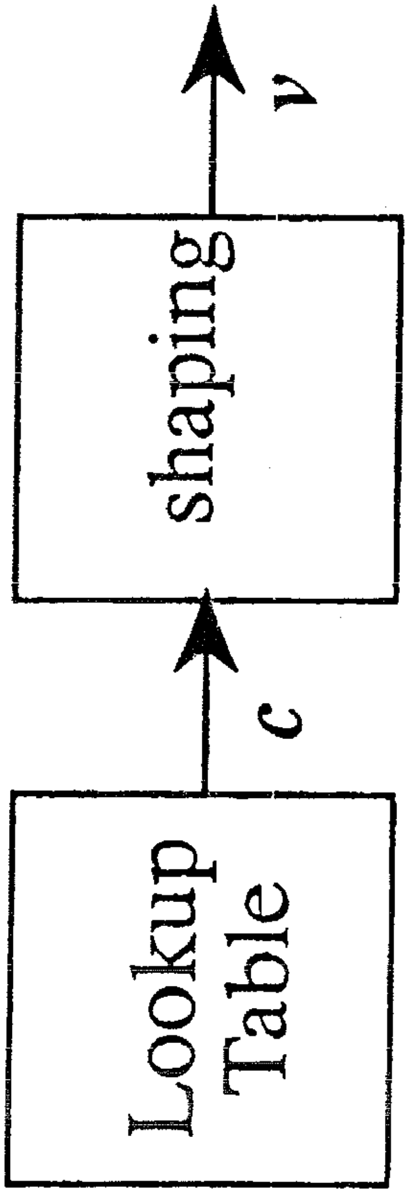


FIGURE 17

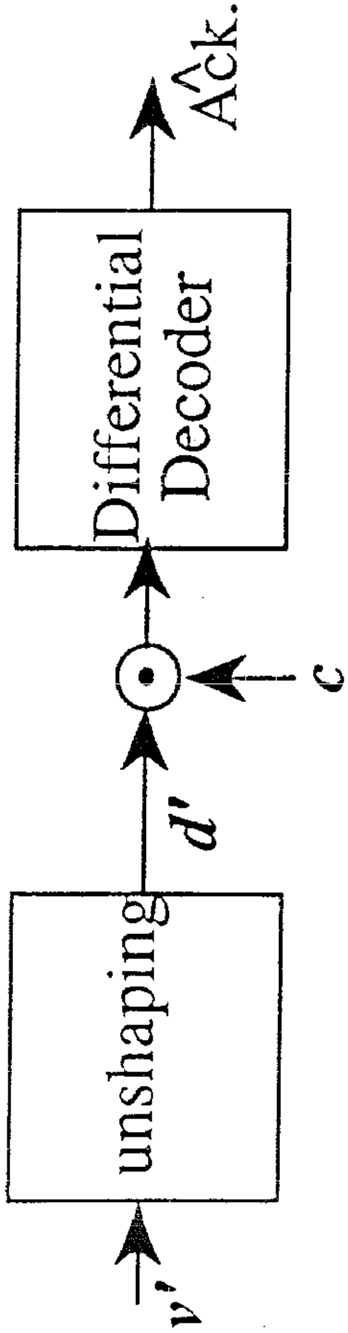


FIGURE 18

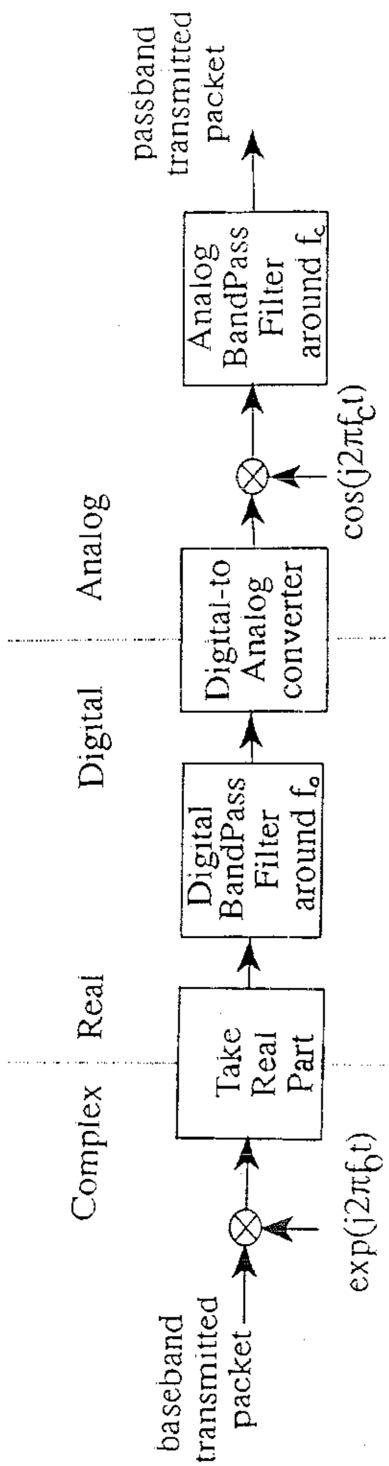

baseband transmitted packet
$\exp(j2\pi f_0 t)$
Complex
Real
Take Real Part
Digital BandPass Filter around f_o
Digital
Analog
Digital-to Analog converter
$\cos(j2\pi f_c t)$
Analog BandPass Filter around f_c
passband transmitted packet

FIGURE 19

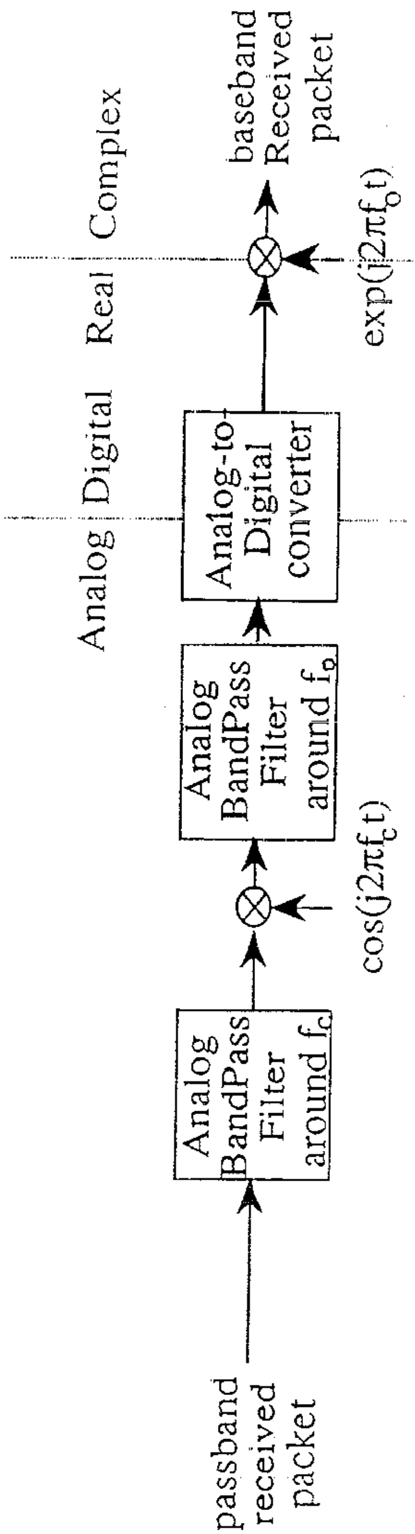

passband
received
packet
Analog
BandPass
Filter
around f_c
$\cos(j2\pi f_c t)$
Analog
BandPass
Filter
around f_o
Analog-to-
Digital
converter
$\exp(j2\pi f_o t)$
baseband
Received
packet
Analog
Digital
Real
Complex

FIGURE 20

MULTICODE DIRECT SEQUENCE SPREAD SPECTRUM

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue

This application is a REISSUE of Ser. No. 08/186,784 filed Jan. 24, 1994 is a continuation-in-part of U.S. application Ser. No. 07/861,725 filed Mar. 31, 1992, now U.S. Pat. No. 5,282,222, the benefit of the filing date of which is hereby claimed under 35 U.S.C. §120

FIELD OF THE INVENTION

The invention deals with the field of multiple access communications using Spread Spectrum modulation. Multiple access can be classified as either random access, polling, TDMA, FDMA, CDMA or any combination thereof. Spread Spectrum can be classified as Direct Sequence, Frequency-Hopping or a combination of the two.

BACKGROUND OF THE INVENTION

Commonly used spread spectrum techniques are Direct Sequence Spread Spectrum (DSSS) and Code Division Multiple Access (CDMA) as explained in Chapter 8 of "Digital Communication" by J. G. Proakis, Second Edition, 1991, McGraw Hill, DSSS is a communication scheme in which information bits are spread over code bits (generally called chips). It is customary to use noise-like codes called pseudo random noise (PN) sequences. These PN sequences have the property that their auto-correlation is almost a delta function and their cross-correlation with other codes is almost null. The advantages of this information spreading are:

1. The transmitted signal can be buried in noise and thus has a low probability of intercept.
2. The receiver can recover the signal from interferers (such as other transmitted codes) with a jamming margin that is proportional to the spreading code length.
3. DSSS codes of duration longer than the delay spread of the propagation channel can lead to multipath diversity implementable using a Rake receiver.
4. The FCC and the DOC have allowed the use of unlicensed low power DSSS systems of code lengths greater than or equal to 10 in some frequency bands (the ISM bands).

It is the last advantage (i.e., advantage 4 above) that has given much interest recently to DSSS.

An obvious limitation of DSSS systems is the limited throughput they can offer. In any given bandwidth, B, a code of length N will reduce the effective bandwidth to B/N. To increase the overall bandwidth efficiency, system designers introduced Code Division Multiple Access (CDMA) where multiple DSSS communication links can be established simultaneously over the same frequency band provided each link uses a unique code that is noise-like. CDMA problems are:

1. The near-far problem: a transmitter "near" the receiver sending a different code than the receiver's desired code produces in the receiver a signal comparable with that of a "far" transmitter sending the desired code.
2. Synchronization of the receiver and the transmitter is complex (especially) if the receiver does not know in advance which code is being transmitted.

SUMMARY OF THE INVENTION

We have recognized that low power DSSS systems complying with the FCC and the DOC regulations for the ISM

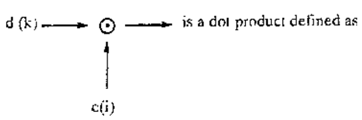
bands would be ideal communicators provided the problems of CDMA could be resolved and the throughput could be enhanced. To enhance the throughput, we allow a single link (i.e., a single transceiver) to use more than one code at the same time. To avoid the near-far problem only one transceiver transmits at a time. In this patent, we present Multi-Code Direct Sequence Spread Spectrum (MC-DSSS) which is a modulation scheme that assigns up to N codes to an individual transceiver where N is the number of chips per DSSS code. When viewed as DSSS, MC-DSSS requires up to N correlators (or equivalently up to N Matched Filters) at the receiver with a complexity of the order of N^2 operations. When N is large, this complexity is prohibitive. In addition, a nonideal communication channel can cause InterCode Interference (ICI), i.e., interference between the N DSSS codes at the receiver. In this patent, we introduce new codes, which we refer to as "MC" codes. Such codes allow the information in a MC-DSSS signal to be decoded in a sequence of low complexity parallel operations while reducing the ICI. In addition to low complexity decoding and ICI reduction, our implementation of MC-DSSS using the MC codes has the following advantages:

1. It does not require the stringent synchronization DSSS requires. Conventional DSSS systems requires synchronization to within a fraction of a chip whereas MC-DSSS using the MC codes requires synchronization to within two chips.
2. It does not require the stringent carrier recovery DSSS requires. Conventional DSSS requires the carrier at the receiver to be phase locked to the received signal whereas MC-DSSS using the MC codes does not require phase locking the carriers. Commercially available crystals have sufficient stability for MC-DSSS.
3. It is spectrally efficient.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic showing for the Baseband Transmitter for the xth MC-DSSS frame: d(k)=[d(1,x) d(2,x) . . . d(N,k)] where c(i)=[c(1,i) c(2,i)] is the ith code and Sym (k)=[sym(1,k) sym(N,k)] is the kth information-bearing vector containing N symbols.

FIG. 2 is a schematic showing a Baseband Receiver for the kth received MC-DSSS frame: d'(k)=[d'(1,k) d'(2,k) . . . d'(N,k)] where c(i)=[c(1,i) c(2,i) . . . c(N,i)] is the ith code, Sym̂(k)=[sym̂(1,k) sym̂(2,k) . . . sym̂(N,k)] is the estimate of the Kth information-bearing vector Sym(k) and



$$d(k) \odot c(i) = c(1,i)d(1,k) = c(2,i)d(2,k) + \ldots + c(N,i)d(N,N).$$

FIG. 3 is a schematic showing of the ith MC code c(i)=[c(i,1) c(i,2) . . . c(i,NO) where i can take one of the N values: 1,2, . . . N corresponding to the position of the single '1' at the input of the first N-point transform.

FIG. 4 is a schematic showing the alternate transmitter for the kth MC-DSSS frame: d(k)=[d(1,k), d(2,k) . . . d(N,k)] using the MC codes generated in FIG. 3 where Sym(k)=[Sym(1,k)Sym(2k) . . . Sym(N,k)] is the kth information-bearing vector contacting N symbols.

FIG. 5 is the alternate receiver for the kth received MC-DSSS frame d'(k)=[d'(1k)d'(2,K) . . . d'(N,k)] using MC codes generated in FIG. 3 where Sym̂(k)=[sym̂(1,k) sym̂(2k) . . . sym̂(N,k)] is the estimate of the information-bearing vetor Sym(k)

FIG. 6 is a schematic showing the Baseband Transmitter of the kth Data Frame X(k) where Sym(N)=[sym(1,k) sym(2,k) . . . sym(N,k)] is the kth information-bearing vector d(k)=[c(1,k) d(2,k) . . . d(N,k)] is the kth MC-DSSS frame v(k)=[v(1,k) v(2,k) . . . v((1+β)MN,k)], β∈(0,1), M=1,2,3 and X(k)=[x(1k) x(2,k)], Z=Z=1, 2, 3.

FIG. 7 is a schematic showing the Baseband Receiver for the kth received Data Frame X'(k) where Sym(N)=[sym(1,k)] sym(2,k) . . . sym(N,k)] is the estimate of the kth information-bearing vector d'(k)=[d'(1,k) d'(2k) . . d'(N,k)] is the kth received MC-DSSS frame v'(k)=[v'(1,k) v(2k) . . . v'((1+β) MN,k)], B∈(0,1), M=1,2,3, and X'(k)=[x'(1,k) x'(2,k) . . . r'(Z,k)], Z=1,2,3

FIG. 8 is a schematic showing the Randomizer Transform (RT) where a (1) a (2) . . . a (N) are complex constants chosen randomly.

FIG. 9 is a schematic showing the Permutation Transform (PT).

FIG. 10 is a schematic showing (a) the shaping of a MC-DSSS frame and (b) the unshaping of a MC-DSSS frame where d(k)=[d(1,k) d(2,k) . . . d(N,k)] is the kth MC-DSSS frame g(k)=[g(1,k) g(2k) . . . g(MN,k)], M=1,2,3, . . . , v(k)=[v(1,k) v(2,k) . . . v((1+β) MN,k)], B∈(0,1) d'(k)=[d(1,k) d(2,k) . . . d(N,K)] is the kth received MC-DSSS frame g'(k)=[g'(1,k) g'(2,k) . . . g'(M'N,k)] and v'(k)=[v(1,k) v'(2,k) . . . v'((1+β) M'N,k)], M'=1,2,3,.

FIG. 11 is a schematic showing (a) Description of the alias/window operation (b) Description of dealias/dewindow operation, where 1/T is the symbol rate.

FIG. 12 is a schematic showing the frame structure for data transmission from source (Node A) to destination (Node B).

FIG. 13 is a schematic showing the baseband transmitter for one request frame v where c=[c(1) c(2) . . . c(1)] is the DSSS code, v=[v(1) v(2) . . . v((1+β)Ml)], β∈(0,1), M=1,2, . . . and l is the length of the DSSS code.

FIG. 14 is a schematic showing the baseband receiver for the received request frame where c=[c(1) c(2) . . . c(1)] is the DSSS code for the request frame, d'=[d(1) d(2) . . . d(1)] is the received request frame, v'=[v'(1) v'((1+β) Ml)], β∈(0,1), M=1,2, . . . and l is the length of the DSSS code.

FIG. 15 is a schematic showing the baseband transmitter for one address frame where c=[c(1) c(2) . . . c(1)] is the CDMA code for the address frame, v=[v(1) v(2) . . . v(1+β) Ml)], β∈(0,1), M=1,2, . . . and l' is the length of the CDMA code.

FIG. 16 is a schematic showing the baseband receiver the address where c=[c(1) c(2) . . . c(l')] is the CDMA code for the address frame, d'=[d(1) d(2) . . . d(l)] is the received address frame, v'[v'(1) v'(2) . . . v'((1+β) Ml')], β∈(0,1), M=1,2, . . . and l' is the length of the CDMA code.

FIG. 17 is a schematic showing the baseband transmitter for Ack. Frame where c=[c(1) c(2) . . . c(l')] is the DSSS code for the Ack frame, v=[v(1) v(2) . . . v((l+β) Ml')] β∈(0,1), M=1,2,3, . . . and l' is the length of the DSSS code.

FIG. 18 is a schematic showing the baseband receiver for the ack frame where c=[c(1) c(2) . . . c(l")] is the DSSS code for the Ack. frame, d'=[d(1) d(2) . . . d'(l")] is the received Ack frame, v'=[v'(1) v(2) . . . v'(1+β) Ml")], β∈(0,1), M=1,2, . . . and l" is the length of the DSSS code.

FIG. 19 is a schematic showing the passband transmitter for a packet where f_c is the IF frequency and f_o+f_c is the RF frequency.

FIG. 20 is a schematic showing the passband receiver for a packet where f_o is the IF frequency and f_o+f_c is the RF frequency.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

FIG. 1 illustrates the transmitter of the MC-DSSS modulation technique generating the kth MC-DSSS frame bearing N symbols of information. The symbols can be either analog or digital.

A converter **10** converts a stream of data symbols into plural sets of N data symbols each. A computing means **12** operates on the plural sets of N data symbols to produce modulated data symbols corresponding to an invertible randomized spreading of the stream of data symbols. A combiner **14** combines the modulated data symbols for transmission. The computing means shown in FIG. **1** includes a source **16** of N direct sequence spread spectrum code symbols and a modulator **18** to modulate each ith data symbol from each set of N data symbols with the I code symbol from the N code symbol to generate N modulated data symbols, and thereby spread each I data symbol over a separate code symbol.

FIG. 2 illustrates the receiver of the MC-DSSS modulation techniques accepting the kth MC-DSSS frame and generating estimates for the corresponding N symbols of information. The dot product in FIG. 2 can be implemented as a correlator. The detector can make either hard decisions or soft decisions.

A sequence of modulated data symbols is received at **22** in which the sequence of modulated data symbols has been generated by the transmitter such as is shown in FIG. **1** or **4**. A second computing means **24** operates on the sequence of modulated data symbols to produce an estimate of the second string of data symbols. The computing means **24** shown in FIG. 2 includes a correlator **26** for correlating each I modulated data symbol from the received sequence of modulated data symbols with the I code symbol from the set of N code symbols and a detector **28** for detecting an estimate of the data symbols from output of the correlator **26**.

FIG. 3 illustrates the code generator of the MC codes. Any one of the P N-point transforms in FIG. **3** consists of a reversible transform to the extent of the available arithmetic precision. In other words, with finite precision arithmetic, the transforms are allowed to add a limited amount of irreversible error.

One can use the MC-DSSS transmitter in FIG. **1** and the MC-DSSS receiver in FIG. **2** together with the MC codes generated using the code generator in FIG. **3** in order to implement MC-DSSS using the MC codes.

An alternative transmitter to the one in FIG. **1** using the MC codes in FIG. 3 is shown in FIG. **4**.

The alternative transmitter shown in FIG. **4** includes a transformer **20** for operating on each set of N data symbols to generate N modulated data symbols as output. A series of transforms are shown.

An alternative receiver to the one in FIG. **2** using the MC codes in FIG. **3** is shown in FIG. **5**. L pilots are required in FIG. **5** for equalization.

Both transmitters in FIGS. **1** and **4** allow using shaper **30** in diversity module **32** shaping and time diversity of the MC-DSSS signal as shown in FIG. **6**. We will refer to the MC-DSSS frame with shaping and time diversity as a Data frame.

Both receivers in FIGS. **2** and **5** allow diversity combining followed by the unshaping of the Data frame as shown in FIG. **7**. A Synch. is required in FIG. **7** for frame synchronization.

In addition to the Data frames, we need to transmit (1) all of the L pilots used in FIG. **5** to estimate and equalize for the various types of channel distortions, (2) the Synch. signal used in FIG. **7** for frame synchronization, and (3) depending on the access technique employed, the source address, destination address and number of Data frames. We will refer to the combination of all transmitted frames as a packet.

PREFERRED EMBODIMENTS OF THE INVENTION

Examples of the N-point transforms in FIG. **3** are a Discrete Fourier Transform (DFT), a Fast Fourier Transform

(FFT), a Walsh Transform (WT), a Hilbert Transform (HT), a Randomizer Transform (RT) as the one illustrated in FIG 8, a Permutator Transform (PT) as the one illustrated in FIG. 9, an Inverse DFT (IDFT), an Inverse FFT (IFFT), an Inverse WT (IWT), an Inverse HT (IHT), an Inverse RT (IRT), an Inverse PT (IPT), and any other reversible transform When L=2 with the first N-point transform being a DFT and the second being a RT, we have a system identical to the patent: "Method and Apparatus for Multiple Access between Transceivers in Wireless Communications using OFDM Spread Spectrum' by M Fattouche and H Zaghloul, filed in the U S Pat Office in Mar. 31, 1992 Ser. No. 07/861,725.

Preferred shaping in FIG 6 consists of an Mth order interpolation filter followed by an alias/window operation as shown in FIG 10a The Alias/window operation is described in FIG 11a where a raised-cosine pulse of rolloff β is applied The interpolation filter in FIG 10a can be implemented as an FIR filter or as an NM-point IDFT where the first N(M−1)/2 points and the last N(M−1)/2 points at the input of the IDFT are zero Preferred values of M are 1,2,3 and 4.

Preferred unshaping in FIG 7 consists of a dealias/dewindow operation followed by a decimation filter as shown in FIG. 10b. The dealias/dewindow operation is described in FIG 11b.

Time Diversity in FIG 6 can consist of repeating the MC-DSSS frame several times It can also consist of repeating the frame several times then complex conjugating some of the replicas, or shifting some of the replicas in the frequency domain in a cyclic manner.

Diversity combining in FIG. 7 can consist of cophasing, selective combining, Maximal Ratio combining or equal gain combining

In FIG 5, L pilots are used to equalize the effects of the channel on each information-bearing data frame. The pilot frames can consist of Data frames of known information symbols to be sent either before, during or after the data, or of a number of samples of known values inserted within two transformations in FIG 4 A preferred embodiment of the pilots is to have the first pilot consisting of a number of frames of known information symbols. The remaining pilots can consist of a number of known information symbols between two transforms. The L estimators can consist of averaging of the pilots followed by either a parametric estimation or a nonparametric one similar to the channel estimator in the patent: "Method and Apparatus for Multiple Access between Transceivers in Wireless Communications using OFDM Spread Spectrum" by M. Fattouche and H Zaghloul, filed in the U S Pat Office in Mar 31, 1992, Ser. No. 07/861,725

When Node A intends to transmit information to Node B, a preferred embodiment of a packet is illustrated in FIG. 12: a Request frame **40**, an Address frame, an Ack frame, a Pilot frame **36** and a number of Data frames **38** The Request frame is used (1) as a wake-up call for all the receivers in the band, (2) for frame synchronization and (3) for packet synchronization It can consist of a DSSS signal using one PN code repeated a number of times and ending with the same PN code with a negative polarity FIGS. **13** and **14** illustrate the transmitter and the receiver for the Request frame respectively. In FIG. **14**, the dot product operation can be implemented as a correlator with either hard or soft decision (or equivalently as a filter matched to the PN code followed by a sample/hold circuit) The Request frame receiver is constantly generating a signal out of the correlator When the signal is above a certain threshold using the level detector, (1) a wake-up call signal is conveyed to the portion of the receiver responsible for the Address frame and (2) the frames are synchronized to the wake-up call. The packet is then synchronized to the negative differential correlation between the last two PN codes in the Request frame using a decoder as shown in FIG. **14**

The Address frame can consist of a CDMA signal where one out of a number of codes is used at a time. The code consists of a number of chips that indicate the destination address, the source address and/or the number of Data frames FIGS. **15** and **16** illustrate the transmitter and the receiver for the Address frame respectively. Each receiver differentially detects the received Address frame, then correlates the outcome with it is own code. If the output of the correlator is above a certain threshold, the receiver instructs its transmitter to transmit an Ack Otherwise, the receiver returns to its initial (idle) state

The Ack frame is a PN code reflecting the status of the receiver, i.e whether it is busy or idle. When it is busy, Node A aborts its transmission and retries some time later. When it is idle, Node A proceeds with transmitting the Pilot frame and the Data frames FIGS. **17** and **18** illustrate the transmitter and the receiver for the Address frame respectively

An extension to the MC-DSSS modulation technique consists of passband modulation where the packet is up-converted from baseband to RF in the transmitter and later down-converted from RF to baseband in the receiver. Passband modulation can be implemented using IF sampling which consists of implementing quadrature modulation/demodulation in an intermediate Frequency between baseband and RF, digitally as shown in FIGS **19** and **20** which illustrate the transmitter and the receiver respectively. IF sampling trades complexity of the analog RF components (at either the transmitter, the receiver or both) with complexity of the digital components Furthermore, in passband systems carrier feed-through is often a problem implying that the transmitter has to ensure a zero dc component. Such a component reduces the usable bandwidth of the channel. In IF sampling the usable band of the channel does not include dc and therefore is the dc component is not a concern

A further extension to the MC-DSSS modulation technique consists of using antenna Diversity in order to improve the Signal-to-Ratio level at the receiver A preferred combining technique is maximal selection combining based on the level of the Request frame at the receiver

We claim:

1. A transceiver for transmitting a first stream of data symbols the transceiver comprising:

a converter for converting the first stream of data symbols into plural sets of N data symbols each;

first computing means for operating on the plural sets of N data symbols to produce modulated data symbols corresponding to an invertible randomized spreading of the first stream of data symbols; and

means to combine the modulated data symbols for transmission

2 The transceiver of claim 1 in which the first computing means [includes] *comprises*:

a source of [N] *more than one and up to M* direct sequence spread spectrum [code symbols] *codes, where M is the number of chips per direct sequence spread spectrum code*; and

a modulator to modulate each [ith] data symbol from each set of [N] data symbols with [the ith] *a* code [symbol] from the [N code symbol] *up to M direct sequence spread spectrum codes* to generate [N] modulated data symbols, and thereby spread each [ith data symbol] *set of data symbols* over a separate code [symbol].

3. The transceiver of claim 2 in which the [code symbols] *direct sequence spread spectrum codes* are generated by operation of a non-trivial [N point] transform on a sequence of input signals

4. The transceiver of claim 1 in which the first computing means [includes] *comprises*:

a transformer for operating on each set of N data symbols to generate [N] modulated data symbols as output, the [N] modulated data symbols corresponding to spreading of each [ith] data symbol over a separate code [symbol] *selected from a set of more than one and up to M codes, where M is the number of chips per code; and*

means to combine the modulated data symbols for transmission.

5. The transceiver of claim 4 in which the transformer effectively applies a first transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform to the N data symbols.

6. The transceiver of claim 5 in which the first transform is a Fourier transform and it is followed by a randomizing transform.

7. The transceiver of claim 6 in which the first transform is a Fourier transform and it is followed by a randomizing transform and a second transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform.

8. The transceiver of claim 4 in which the transformer effectively applies a first inverse transform selected from the group [comprising] *consisting of* a randomizer transform, a Fourier transform and a Walsh transform to the N data symbols, followed by a first equalizer and a second inverse transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform.

9. The transceiver of claim 8 in which the second transform is followed by a second equalizer.

10. The transceiver of claim 1 further [including] *comprising*:

means for receiving a sequence of modulated data symbols, the modulated data symbols having been generated by invertible randomized spreading of a second stream of data symbols; *and*

second computing means for operating on the sequence of modulated data symbols to produce an estimate of the second stream of data symbols.

11. The transceiver of claim 10 further [including] *comprising* means to apply diversity to the modulated data symbols before transmission, and means to combine received diversity signals.

12. The transceiver of claim 10 in which the second computing means [includes] *comprises*:

a correlator for correlating each [ith] modulated data symbol from the received sequence of modulated data symbols with [the ith code symbol] *a code* from [the] *a* set of [N code symbols] *more than one and up to M codes, where M is the number of chips per code*; and

a detector for detecting an estimate of the data symbols from output of the correlator.

13. The transceiver of claim 10 in which the second computing means [includes] *comprises* an inverse transformer for regenerating an estimate of the [N] data symbols.

14. The transceiver of claim 1 further [including] *comprising* a shaper for shaping the combined modulated data symbols for transmission.

15. The transceiver of claim 1 further [including] *comprising* means to apply diversity to the combined modulated data symbols before transmission.

16. The transceiver of claim 1 in which the [N] data symbols include a pilot frame and a number of data frames, and is preceded by a request frame, wherein the request frame is used to wake up receiving transceivers, synchronize reception of the [N] data symbols and convey protocol information.

17. A transceiver for transmitting a first stream of data symbols and receiving a second stream of data symbols, the transceiver comprising:

a converter for converting the first stream of data symbols into plural sets of N data symbols each;

first computing means for operating on the plural sets of N data symbols to produce sets of [N] modulated data symbols corresponding to an invertible randomized spreading of each set of N data symbols over [N code symbols] *more than one and up to M direct sequence spread spectrum codes;*

means to combine the modulated data symbols for transmission;

means for receiving a sequence of modulated data symbols, the modulated data symbols having been generated by an invertible randomized spreading of a second stream of data symbols over [N code symbols] *more than one and up to M direct sequence spread spectrum codes*;

second computing means for operating on the sequence of modulated data symbols to produce an estimate of the second stream of data symbols; and

means to combine output from the second computing means.

18. The transceiver of claim 17 in which the first computing means [includes] *comprises*:

a source of [N] *the* direct sequence spread spectrum [code symbols] *codes*; and

a modulator to modulate each [ith] data symbol from each set of N data symbols with [the ith code symbol] *a code* from the [N code symbol] *up to M direct sequence spread spectrum codes* to generate [N] modulated data symbols, and thereby spread each [ith] data symbol over a separate *direct sequence spread spectrum* code [symbol].

19. The transceiver of claim 18 in which the [code symbols] *direct sequence spread spectrum codes* are generated by operation of plural non-trivial [N point] transforms on a random sequence of input signals.

20. The transceiver of claim 17 in which the first computing means [includes] *comprises*:

a transformer for operating on each set of N data symbols to generate [N] modulated data symbols as output, the [N] modulated data symbols corresponding to spreading of each [ith] data symbol over a separate code [symbol].

21. The transceiver of claim 17 in which the second computing means [includes] *comprises*:

a correlator for correlating each [ith] modulated data symbol from the received sequence of modulated data symbols with [the ith code symbol] *a code* from the [set of N code symbols] *up to M direct sequence spread spectrum codes*; and

a detector for detecting an estimate of the data symbols from the output of the correlator.

22. The transceiver of claim 17 in which the second computing means [includes] *comprises* an inverse transformer for regenerating an estimate of the N data symbols.

23. A method of exchanging data streams between a plurality of transceivers, the method comprising the steps of:

converting a first stream of data symbols into plural sets of N data symbols each;

operating on the plural sets of N data symbols to produce modulated data symbols corresponding to a spreading of the first stream of data symbols over [N code symbols] *more than one and up to M direct sequence spread spectrum codes*;

combining the modulated data symbols for transmission; and

transmitting the modulated data symbols from a first transceiver at a time when no other of the plurality of transceivers is transmitting

24. The method of claim 23 in which the spreading is an invertible randomized spreading and operating on the plural sets of N data symbols [includes] *comprises* modulating each [ith] data symbol from each set of N data symbols with [the ith code symbol] *a code* from the [N code symbols] *up to M direct sequence spread spectrum codes* to generate [N] modulated data symbols, and thereby spread each [ith] data symbol over a separate code [symbol].

25. The method of claim 23 in which the spreading is an invertible randomized spreading and operating on the plural sets of N data symbols [includes] *comprises*:

transforming, by application of a transform, each set of N data symbols to generate [N] modulated data symbols as output.

26. The method of claim 25 in which transforming each set of N data symbols [includes] *comprises* applying to each set of N data symbols a randomizing transform and a transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform

27. The method of claim 25 in which transforming each set of N data symbols [includes] *comprises* applying to each set of N data symbols a Fourier transform, a randomizing transform and a transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform

28. The method of claim 25 in which transforming each set of N data symbols [includes] *comprises* applying to each set of N data symbols a first transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform, a randomizing transform and a second transform selected from the group [comprising] *consisting of* a Fourier transform and a Walsh transform.

29 The method of claim 23 further [including] *comprising* the step of:

receiving, at a transceiver distinct from the first transceiver, the sequence of modulated data symbols; and

operating on the sequence of modulated data symbols to produce an estimate of the first stream of data symbols

30 The method of claim 29 in which operating on the sequence of modulated data symbols [includes] *comprises* the steps of:

correlating each [ith] modulated data symbol from the received sequence of modulated data symbols with [the ith code symbol from the set of N code symbols] *a code from the up to M direct sequence spread spectrum codes*; and

detecting an estimate of the first stream of data symbols from output of the correlator

31. The method of claim 23 further [including] *comprising the step of* shaping the modulated data symbols before transmission

32. The method of claim 23 further [including] *comprising the step of* applying diversity to the modulated data symbols before transmission

33 A transceiver for transmitting a first stream of data symbols, the transceiver comprising

a converter for converting the first stream of data symbols into plural sets of data symbols each;

first computing means for operating on the plural sets of data symbols to produce modulated data symbols corresponding to an invertible randomized spreading of the first stream of data symbols over more than one and up to M direct sequence spread spectrum codes, where each direct sequence spread spectrum code has M chips; and

means to combine the modulated data symbols for transmission

34 The transceiver of claim 33 further comprising

means for receiving a sequence of modulated data symbols, the modulated data symbols having been generated by invertible randomized spreading of a second stream of data symbols; and

second computing means for operating on the sequence of modulated data symbols to produce an estimate of the second stream of data symbols

35 The transceiver of claim 34 further comprising means to apply diversity to the modulated data symbols before transmission, and means to combine received diversity signals.

36 The transceiver of claim 34 in which the second computing means comprises

a correlator for correlating each modulated data symbol from the received sequence of modulated data symbols with a code from the set of up to M direct sequence spread spectrum codes; and

a detector for detecting an estimate of the data symbols from output of the correlator.

37. The transceiver of claim 34 in which the second computing means comprises an inverse transformer for regenerating an estimate of the data symbols.

38 The transceiver of claim 33 further comprising a shaper for shaping the combined modulated data symbols for transmission

39 The transceiver of claim 33 further comprising means to apply diversity to the combined modulated data symbols before transmission

40 The transceiver of claim 33 in which the data symbols include a pilot frame and a number of data frames, and is preceded by a request frame, wherein the request frame is used to wake up receiving transceivers, synchronize reception of the data symbols and convey protocol information

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : RE 37,802 E
DATED : July 23, 2002
INVENTOR(S) : M T. Fattouche et al

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [63], **Related U.S. Application Data**, insert in appropriate order

-- **Related U.S. Application Data**
[63] Continuation-in-part of U.S application
No. 07/861,725, filed on Mar 31, 1992, now Pat
No. 5,282,222 --

Signed and Sealed this

Eleventh Day of March, 2003

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

Case 2:07-cv-00473-TJW Document 1-3 Filed 10/31/2007 Page 1 of 2

JS 44 (Rev 11/04)

CIVIL COVER SHEET

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974 is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM)

RECEIVED-CLERK

I. (a) PLAINTIFFS

Wi-LAN Inc

EASTERN-MARSHALL

(b) County of Residence of First Listed Plaintiff Ontario, Canada
(EXCEPT IN U S PLAINTIFF CASES)

(c) Attorney's (Firm Name Address and Telephone Number)
Sam Baxter, McKool Smith, P C , 104 East Houston St , Suite 300
P.O. Box 0, Marshall, Texas 75670 (903) 923-9000

DEFENDANTS

See Attachment "A"

2-07CV-473

County of Residence of First Listed Defendant
(IN U S PLAINTIFF CASES ONLY)
NOTE: IN LAND CONDEMNATION CASES USE THE LOCATION OF THE LAND INVOLVED

Attorneys (If Known)

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

☐ 1 U S. Government Plaintiff
☒ 3 Federal Question (U S Government Not a Party)
☐ 2 U S. Government Defendant
☐ 4 Diversity (Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant) (For Diversity Cases Only)

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated *or* Principal Place of Business In This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated *and* Principal Place of Business In Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. NATURE OF SUIT (Place an "X" in One Box Only)

CONTRACT
☐ 110 Insurance
☐ 120 Marine
☐ 130 Miller Act
☐ 140 Negotiable Instrument
☐ 150 Recovery of Overpayment & Enforcement of Judgment
☐ 151 Medicare Act
☐ 152 Recovery of Defaulted Student Loans (Excl Veterans)
☐ 153 Recovery of Overpayment of Veteran's Benefits
☐ 160 Stockholders' Suits
☐ 190 Other Contract
☐ 195 Contract Product Liability
☐ 196 Franchise

REAL PROPERTY
☐ 210 Land Condemnation
☐ 220 Foreclosure
☐ 230 Rent Lease & Ejectment
☐ 240 Torts to Land
☐ 245 Tort Product Liability
☐ 290 All Other Real Property

TORTS

PERSONAL INJURY
☐ 310 Airplane
☐ 315 Airplane Product Liability
☐ 320 Assault Libel & Slander
☐ 330 Federal Employers Liability
☐ 340 Marine
☐ 345 Marine Product Liability
☐ 350 Motor Vehicle
☐ 355 Motor Vehicle Product Liability
☐ 360 Other Personal Injury

PERSONAL INJURY
☐ 362 Personal Injury - Med. Malpractice
☐ 365 Personal Injury - Product Liability
☐ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
☐ 370 Other Fraud
☐ 371 Truth in Lending
☐ 380 Other Personal Property Damage
☐ 385 Property Damage Product Liability

CIVIL RIGHTS
☐ 441 Voting
☐ 442 Employment
☐ 443 Housing/ Accommodations
☐ 444 Welfare
☐ 445 Amer w/Disabilities - Employment
☐ 446 Amer w/Disabilities - Other
☐ 440 Other Civil Rights

PRISONER PETITIONS
☐ 510 Motions to Vacate Sentence
Habeas Corpus:
☐ 530 General
☐ 535 Death Penalty
☐ 540 Mandamus & Other
☐ 550 Civil Rights
☐ 555 Prison Condition

FORFEITURE/PENALTY
☐ 610 Agriculture
☐ 620 Other Food & Drug
☐ 625 Drug Related Seizure of Property 21 USC 881
☐ 630 Liquor Laws
☐ 640 R.R. & Truck
☐ 650 Airline Regs.
☐ 660 Occupational Safety/Health
☐ 690 Other

LABOR
☐ 710 Fair Labor Standards Act
☐ 720 Labor/Mgmt Relations
☐ 730 Labor/Mgmt Reporting & Disclosure Act
☐ 740 Railway Labor Act
☐ 790 Other Labor Litigation
☐ 791 Empl. Ret Inc Security Act

BANKRUPTCY
☐ 422 Appeal 28 USC 158
☐ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
☐ 820 Copyrights
☒ 830 Patent
☐ 840 Trademark

SOCIAL SECURITY
☐ 861 HIA (1395ff)
☐ 862 Black Lung (923)
☐ 863 DIWC/DIWW (405(g))
☐ 864 SSID Title XVI
☐ 865 RSI (405(g))

FEDERAL TAX SUITS
☐ 870 Taxes (U.S. Plaintiff or Defendant)
☐ 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
☐ 400 State Reapportionment
☐ 410 Antitrust
☐ 430 Banks and Banking
☐ 450 Commerce
☐ 460 Deportation
☐ 470 Racketeer Influenced and Corrupt Organizations
☐ 480 Consumer Credit
☐ 490 Cable/Sat TV
☐ 810 Selective Service
☐ 850 Securities/Commodities/ Exchange
☐ 875 Customer Challenge 12 USC 3410
☐ 890 Other Statutory Actions
☐ 891 Agricultural Acts
☐ 892 Economic Stabilization Act
☐ 893 Environmental Matters
☐ 894 Energy Allocation Act
☐ 895 Freedom of Information Act
☐ 900 Appeal of Fee Determination Under Equal Access to Justice
☐ 950 Constitutionality of State Statutes

V. ORIGIN (Place an X in One Box Only)

☒ 1 Original Proceeding ☐ 2 Removed from State Court ☐ 3 Remanded from Appellate Court ☐ 4 Reinstated or Reopened ☐ 5 Transferred from another district (specify) ☐ 6 Multidistrict Litigation ☐ 7 Appeal to District Judge from Magistrate Judgment

VI. CAUSE OF ACTION

Cite the U S Civil Statute under which you are filing (**Do not cite jurisdictional statutes unless diversity**):

Brief description of cause: 35 USC 271; Infringement of Patent

VII. REQUESTED IN COMPLAINT:

☐ CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23

DEMAND $

CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ Yes ☐ No

VIII. RELATED CASE(S) IF ANY

(See instructions): JUDGE DOCKET NUMBER

DATE 10/31/07

SIGNATURE OF ATTORNEY OF RECORD Sam Baxter

FOR OFFICE USE ONLY

RECEIPT # AMOUNT APPLYING IFP JUDGE MAG JUDGE

ATTACHMENT "A"

1. Acer, Inc.
2. Acer America Corporation
3. Apple, Inc.
4. Dell, Inc.
5. Gateway, Inc.
6. Hewlett-Packard Company
7. Lenovo Group Ltd.
8. Lenovo (United States) Inc.
9. Sony Corporation
10. Sony Corporation of America
11. Sony Electronics, Inc.
12. Sony Computer Entertainment America, Inc.
13. Toshiba Corporation
14. Toshiba America, Inc.
15. Toshiba America Information Systems, Inc.
16. Broadcom Corporation
17. Intel Corporation
18. Atheros Communications, Inc.
19. Marvell Semiconductor, Inc.
20. Best Buy Co., Inc.
21. Circuit City Stores, Inc.

IN THE UNITED STATES DISTRICT COURT
EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

WI-LAN INC., Plaintiff, v. WESTELL TECHNOLOGIES, INC., ET AL., Defendants.	Civil Action No. 2:07-CV-474-TJW **Jury Trial Demanded**

MARVELL SEMICONDUCTOR, INC.'S ANSWER AND COUNTERCLAIMS TO WI-LAN INC.'S COMPLAINT FOR PATENT INFRINGEMENT

Defendant Marvell Semiconductor, Inc. ("Marvell") responds to the Original Complaint for Patent Infringement of Plaintiff Wi-LAN Inc. ("Wi-LAN") as follows:

ANSWER

1. On information and belief, Marvell admits that Wi-LAN is a corporation existing under the laws of Canada with its principal place of business at 11 Holland Ave., Suite 608, Ottawa, Ontario, Canada.

2. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 2, and, therefore, denies those allegations.

3. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 3, and, therefore, denies those allegations.

4. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 4, and, therefore, denies those allegations.

5. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 5, and, therefore, denies those allegations.

6. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 6, and, therefore, denies those allegations.

7. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 7, and, therefore, denies those allegations.

8. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 8, and, therefore, denies those allegations.

9. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 9, and, therefore, denies those allegations.

10. Marvell admits that it is a California Corporation with its principal place of business at 5488 Marvell Lane, Santa Clara, CA 95054-3606. Marvell also admits that it may be served with process by serving its registered agent, CT Corporation System, at 818 West Seventh Street, Los Angeles, California 90017. Except as expressly admitted, Marvell denies the remaining allegations of paragraph 10.

11. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 11, and, therefore, denies those allegations.

12. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 12, and, therefore, denies those allegations.

13. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 13, and, therefore, denies those allegations.

14. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 14, and, therefore, denies those allegations.

15. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 15, and, therefore, denies those allegations.

16. Marvell admits the allegations of paragraph 16.

17. Marvell admits that this Court has subject matter jurisdiction over this action pursuant to 28 U.S.C. §§ 1331 and 1338(a).

18. Marvell admits for purposes of this action only that this Court has personal jurisdiction as to Marvell. Marvell denies that it has committed the tort of patent infringement within the State of Texas or within the Eastern District of Texas or elsewhere. Except as expressly admitted, Marvell denies the remaining allegations of paragraph 18 that relate to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 18 that relate to other defendants, and, therefore, denies those allegations.

19. Marvell admits for purposes of this action only that venue is proper in this Court pursuant to 28 U.S.C. §§ 1391 and 1400(b).

20. Marvell admits that U.S. Patent No. 5,282,222 ("the '222 patent") bears an issue date of January 25, 1994, and is entitled "Method and Apparatus for Multiple Access Between Transceivers in Wireless Communications Using OFDM Spread Spectrum." Marvell denies that the '222 patent was duly and legally issued. Marvell lacks sufficient knowledge or belief to admit or deny the remaining allegations of paragraph 20, and, therefore, denies those allegations.

21. Marvell admits that U.S. Patent No. RE37,802 ("the '802 patent") bears an issue date of July 23, 2002, and is entitled "Multicode Direct Sequence Spread Spectrum." Marvell denies that the '802 patent was duly and legally issued. Marvell lacks sufficient knowledge or belief to admit or deny the remaining allegations of paragraph 21, and, therefore, denies those allegations.

22. Marvell admits that U.S. Patent No. 5,956,323 ("the '323 patent") bears an issue date of September 21, 1999, and is entitled "Power Conservation for POTS and Modulated Data Transmission." Marvell lacks sufficient knowledge or belief to admit or deny the remaining allegations of paragraph 22, and, therefore, denies those allegations.

23. Marvell denies the allegations of paragraph 23 as they pertain to the '222 patent and the '802 patent. Marvell lacks sufficient knowledge or belief to admit or deny the remaining allegations of paragraph 23, and, therefore, denies those allegations.

24. To the extent that the allegations of paragraph 24 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 24 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

25. To the extent that the allegations of paragraph 25 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 25 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

26. To the extent that the allegations of paragraph 26 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 26 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

27. To the extent that the allegations of paragraph 27 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 27 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

28. To the extent that the allegations of paragraph 28 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 28 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

29. To the extent that the allegations of paragraph 29 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 29 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

30. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 30, and, therefore, denies those allegations.

31. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 31, and, therefore, denies those allegations.

32. Marvell denies the allegations in paragraph 32.

33. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 33, and, therefore, denies those allegations.

34. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 34, and, therefore, denies those allegations.

35. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 35, and, therefore, denies those allegations.

36. To the extent that the allegations of paragraph 36 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 36 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

37. To the extent that the allegations of paragraph 37 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 37 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

38. Marvell denies the allegations of paragraph 38 that relate to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 38 that relate to other defendants, and, therefore, denies those allegations.

39. Marvell denies the allegations of paragraph 39 that relate to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 39 that relate to other defendants, and, therefore, denies those allegations.

40. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 40, and, therefore, denies those allegations.

41. Marvell denies the allegations of paragraph 41 that relate to Marvell and denies causing Wi-LAN to suffer any damages. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 41 that relate to other defendants, and, therefore, denies those allegations.

PLAINTIFF'S PRAYER FOR RELIEF

Marvell denies the allegations of Wi-LAN's Prayer for Relief against Marvell and denies that Wi-LAN is entitled to any relief whatsoever with respect to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of Wi-LAN's Prayer for Relief that relate to other defendants, and, therefore, denies those allegations.

PLAINTIFF'S DEMAND FOR JURY TRIAL

Marvell acknowledges that Wi-LAN has demanded a jury trial.

AFFIRMATIVE DEFENSES

FIRST AFFIRMATIVE DEFENSE

42. Marvell's accused products do not and have not infringed (either directly, contributorily, or by inducement) any claim of the '222 patent or the '802 patent.

SECOND AFFIRMATIVE DEFENSE

43. One or more asserted claims of the '222 patent and the '802 patent are invalid because they fail to comply with the requirements 35 U.S.C. § 101 *et seq.*, including, without limitation, sections 102, 103, 112 and/or 116.

THIRD AFFIRMATIVE DEFENSE

44. Wi-LAN's claims are barred, in whole or in part, by the equitable doctrines of laches, unclean hands, estoppel and/or waiver.

FOURTH AFFIRMATIVE DEFENSE

45. Wi-LAN's claims are barred by the doctrine of prosecution history estoppel based on statements, representations and admissions made during prosecution of the patent applications resulting in the '222 and '802 patents.

FIFTH AFFIRMATIVE DEFENSE

46. Wi-LAN's claims for damages are statutorily limited by 35 U.S.C. §§ 286 and/or 287.

SIXTH AFFIRMATIVE DEFENSE

47. Wi-LAN's claim for injunctive relief is barred because there exists an adequate remedy at law and Wi-LAN's claims otherwise fail to meet the requirements for such relief.

MARVELL'S COUNTERCLAIM FOR DECLARATORY RELIEF

Marvell asserts the following counterclaim for declaratory relief against Wi-LAN:

PARTIES

48. Marvell is a California corporation, with its principal place of business located at 5488 Marvell Lane, Santa Clara, CA 95054.

49. On information and belief, Wi-LAN is a Canadian corporation, with its principal place of business at 11 Holland Ave., Suite 608, Ottawa, Ontario, Canada.

JURISDICTION AND VENUE

50. This counterclaim for a declaratory judgment arises under the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq.*, and the Patent Act of the United States, 35 U.S.C. § 101 *et seq*. This Court also has personal jurisdiction over Wi-LAN because, among other reasons, Wi-LAN submitted itself to the jurisdiction of this Court by bringing its complaint for infringement of the '222 patent and the '802 patent in this Court.

51. Venue is proper in this District pursuant to 28 U.S.C. §§ 1391 and 1400(b) because, among other reasons, Wi-LAN has brought its complaint for infringement of the '222 patent and the '802 patent in this Court.

COUNT I:

DECLARATORY RELIEF REGARDING NON-INFRINGEMENT

52. An actual and justiciable controversy exists between Marvell and Wi-LAN as to the non-infringement of the '222 patent and the '802 patent, as evidenced by Wi-LAN's Complaint and Marvell's Answer to that Complaint, set forth above.

53. Pursuant to the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq*., Marvell requests a declaration of the Court that Marvell's accused products do not infringe and have not infringed any valid claim of the '222 patent or the '802 patent.

COUNT II:

DECLARATORY RELIEF REGARDING INVALIDITY

54. An actual and justiciable controversy exists between Marvell and Wi-LAN as to the invalidity of the '222 patent and the '802 patent, as evidenced by Wi-LAN's Complaint and Marvell's Answer to that Complaint, set forth above.

55. Pursuant to the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq*., Marvell requests a declaration of the Court that the '222 patent and the '802 patent are invalid.

WHEREFORE, Marvell prays for judgment as follows:

1. That Wi-LAN take nothing by its Complaint;

2. That Wi-LAN's Complaint be dismissed with prejudice;

3. That the Court enter a declaration that Marvell's accused products do not infringe and have not infringed, directly or indirectly, any valid claim of the '222 patent or the '802 patent;

4. That the Court declare that the '222 patent and the '802 patent are invalid;

5. That this case be declared exceptional and Marvell be awarded its costs, expenses and reasonable attorney fees in this action pursuant 35 U.S.C. § 285; and

6. That Marvell be awarded such other and further relief as the Court may deem appropriate.

DEMAND FOR JURY TRIAL

Defendant Marvell Semiconductor, Inc. hereby demands a jury trial as to all issues triable by jury.

Date: January 25, 2008

Respectfully submitted,

/s/ Jennifer Parker Ainsworth

Jennifer Parker Ainsworth
State Bar No. 00784720
WILSON, ROBERTSON & CORNELIUS, P.C.
P.O. Box 7339
Tyler, Texas 75711
(903) 509-5000
(903) 509-5092 (facsimile)
jainsworth@wilsonlawfirm.com

ATTORNEYS FOR DEFENDANT
MARVELL SEMICONDUCTOR, INC.

CERTIFICATE OF SERVICE

The undersigned certifies that the foregoing document was filed electronically in compliance with Local Rule CV-5(a). As such, this motion was served on all counsel who have consented to electronic service, Local Rule CV-5(a)(3)(A), on this the 25th day of January, 2008.

/s/ Jennifer P. Ainsworth
Jennifer P. Ainsworth

IN THE UNITED STATES DISTRICT COURT
EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

WI-LAN INC., Plaintiff, v. ACER, INC., ET AL., Defendants.	Civil Action No. 2:07-CV-473-TJW **Jury Trial Demanded**

<u>MARVELL SEMICONDUCTOR, INC.'S ANSWER AND COUNTERCLAIMS TO WI-LAN INC.'S COMPLAINT FOR PATENT INFRINGEMENT</u>

Defendant Marvell Semiconductor, Inc. ("Marvell") responds to the Original Complaint for Patent Infringement of Plaintiff Wi-LAN Inc. ("Wi-LAN") as follows:

<u>ANSWER</u>

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2. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 2, and, therefore, denies those allegations.

3. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 3, and, therefore, denies those allegations.

4. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 4, and, therefore, denies those allegations.

5. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 5, and, therefore, denies those allegations.

6. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 6, and, therefore, denies those allegations.

7. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 7, and, therefore, denies those allegations.

8. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 8, and, therefore, denies those allegations.

9. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 9, and, therefore, denies those allegations.

10. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 10, and, therefore, denies those allegations.

11. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 11, and, therefore, denies those allegations.

12. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 12, and, therefore, denies those allegations.

13. Marvell admits that it is a California Corporation with its principal place of business at 5488 Marvell Lane, Santa Clara, CA 95054-3606. Marvell also admits that it may be served with process by serving its registered agent, CT Corporation System, at 818 West Seventh Street, Los Angeles, California 90017. Except as expressly admitted, Marvell denies the remaining allegations of paragraph 13.

14. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 14, and, therefore, denies those allegations.

15. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 15, and, therefore, denies those allegations.

16. Marvell admits the allegations of paragraph 16.

17. Marvell admits that this Court has subject matter jurisdiction over this action pursuant to 28 U.S.C. §§ 1331 and 1338(a).

18. Marvell admits for purposes of this action only that this Court has personal jurisdiction as to Marvell. Marvell denies that it has committed the tort of patent infringement within the State of Texas or within the Eastern District of Texas or elsewhere. Except as expressly admitted, Marvell denies the remaining allegations of paragraph 18 that relate to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 18 that relate to other defendants, and, therefore, denies those allegations.

19. Marvell admits for purposes of this action only that venue is proper in this Court pursuant to 28 U.S.C. §§ 1391 and 1400(b).

20. Marvell admits that U.S. Patent No. 5,282,222 ("the '222 patent") bears an issue date of January 25, 1994, and is entitled "Method and Apparatus for Multiple Access Between Transceivers in Wireless Communications Using OFDM Spread Spectrum." Marvell denies that the '222 patent was duly and legally issued. Marvell lacks sufficient knowledge or belief to admit or deny the remaining allegations of paragraph 20, and, therefore, denies those allegations.

21. Marvell admits that U.S. Patent No. RE37,802 ("the '802 patent") bears an issue date of July 23, 2002, and is entitled "Multicode Direct Sequence Spread Spectrum." Marvell denies that the '802 patent was duly and legally issued. Marvell lacks sufficient knowledge or belief to admit or deny the remaining allegations of paragraph 21, and, therefore, denies those allegations.

22. Marvell denies the allegations of paragraph 22.

23. To the extent that the allegations of paragraph 23 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 23 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

24. To the extent that the allegations of paragraph 24 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 24 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

25. To the extent that the allegations of paragraph 25 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 25 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

26. To the extent that the allegations of paragraph 26 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 26 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

27. To the extent that the allegations of paragraph 27 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 27 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

28. To the extent that the allegations of paragraph 28 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 28 relate to non-

Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

29. To the extent that the allegations of paragraph 29 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 29 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

30. To the extent that the allegations of paragraph 30 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 30 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

31. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 31, and, therefore, denies those allegations.

32. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 32, and, therefore, denies those allegations.

33. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 33, and, therefore, denies those allegations.

34. Marvell denies the allegations in paragraph 34.

35. To the extent that the allegations of paragraph 35 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 35 relate to non-Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

36. To the extent that the allegations of paragraph 36 relate to Marvell products, Marvell denies those allegations. To the extent that the allegations of paragraph 36 relate to non-

Marvell products, Marvell lacks sufficient knowledge or belief to admit or deny those allegations, and, therefore, denies those allegations.

37. Marvell denies the allegations of paragraph 37 that relate to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 37 that relate to other defendants, and, therefore, denies those allegations.

38. Marvell denies the allegations of paragraph 38 that relate to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 38 that relate to other defendants, and, therefore, denies those allegations.

39. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 39, and, therefore, denies those allegations.

40. Marvell denies the allegations of paragraph 40 that relate to Marvell and denies causing Wi-LAN to suffer any damages. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of paragraph 40 that relate to other defendants, and, therefore, denies those allegations.

PLAINTIFF'S PRAYER FOR RELIEF

Marvell denies the allegations of Wi-LAN's Prayer for Relief against Marvell and denies that Wi-LAN is entitled to any relief whatsoever with respect to Marvell. Marvell lacks sufficient knowledge or belief to admit or deny the allegations of Wi-LAN's Prayer for Relief that relate to other defendants, and, therefore, denies those allegations.

PLAINTIFF'S DEMAND FOR JURY TRIAL

Marvell acknowledges that Wi-LAN has demanded a jury trial.

AFFIRMATIVE DEFENSES

FIRST AFFIRMATIVE DEFENSE

41. Marvell's accused products do not and have not infringed (either directly, contributorily, or by inducement) any claim of the '222 patent or the '802 patent (collectively "the patents-in-suit").

SECOND AFFIRMATIVE DEFENSE

42. One or more asserted claims of the patents-in-suit are invalid because they fail to comply with the requirements 35 U.S.C. § 101 *et seq.*, including, without limitation, sections 102, 103, 112 and/or 116.

THIRD AFFIRMATIVE DEFENSE

43. Wi-LAN's claims are barred, in whole or in part, by the equitable doctrines of laches, unclean hands, estoppel and/or waiver.

FOURTH AFFIRMATIVE DEFENSE

44. Wi-LAN's claims are barred by the doctrine of prosecution history estoppel based on statements, representations and admissions made during prosecution of the patent applications resulting in the patents-in-suit.

FIFTH AFFIRMATIVE DEFENSE

45. Wi-LAN's claims for damages are statutorily limited by 35 U.S.C. §§ 286 and/or 287.

SIXTH AFFIRMATIVE DEFENSE

46. Wi-LAN's claim for injunctive relief is barred because there exists an adequate remedy at law and Wi-LAN's claims otherwise fail to meet the requirements for such relief.

MARVELL'S COUNTERCLAIM FOR DECLARATORY RELIEF

Marvell asserts the following counterclaim for declaratory relief against Wi-LAN:

PARTIES

47. Marvell is a California corporation, with its principal place of business located at 5488 Marvell Lane, Santa Clara, CA 95054.

48. On information and belief, Wi-LAN is a Canadian corporation, with its principal place of business at 11 Holland Ave., Suite 608, Ottawa, Ontario, Canada.

JURISDICTION AND VENUE

49. This counterclaim for a declaratory judgment arises under the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq.*, and the Patent Act of the United States, 35 U.S.C. § 101 *et seq*. This Court also has personal jurisdiction over Wi-LAN because, among other reasons, Wi-LAN submitted itself to the jurisdiction of this Court by bringing its complaint for infringement of the patents-in-suit in this Court.

50. Venue is proper in this District pursuant to 28 U.S.C. §§ 1391 and 1400(b) because, among other reasons, Wi-LAN has brought its complaint for infringement of the patents-in-suit in this Court.

COUNT I:

DECLARATORY RELIEF REGARDING NON-INFRINGEMENT

51. An actual and justiciable controversy exists between Marvell and Wi-LAN as to the non-infringement of the patents-in-suit, as evidenced by Wi-LAN's Complaint and Marvell's Answer to that Complaint, set forth above.

52. Pursuant to the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq*., Marvell requests a declaration of the Court that Marvell's accused products do not infringe and have not infringed any valid claim of the patents-in-suit.

COUNT II:

DECLARATORY RELIEF REGARDING INVALIDITY

53. An actual and justiciable controversy exists between Marvell and Wi-LAN as to the invalidity of the patents-in-suit, as evidenced by Wi-LAN's Complaint and Marvell's Answer to that Complaint, set forth above.

54. Pursuant to the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq*., Marvell requests a declaration of the Court that the patents-in-suit are invalid.

WHEREFORE, Marvell prays for judgment as follows:

1. That Wi-LAN take nothing by its Complaint;

2. That Wi-LAN's Complaint be dismissed with prejudice;

3. That the Court enter a declaration that Marvell's accused products do not infringe and have not infringed, directly or indirectly, any valid claim of the patents-in-suit;

4. That the Court declare that the patents-in-suit are invalid;

5. That this case be declared exceptional and Marvell be awarded its costs, expenses and reasonable attorney fees in this action pursuant 35 U.S.C. § 285; and

6. That Marvell be awarded such other and further relief as the Court may deem appropriate.

DEMAND FOR JURY TRIAL

Defendant Marvell Semiconductor, Inc. hereby demands a jury trial as to all issues triable by jury.

Date: January 25, 2008

Respectfully submitted,

*/s/ Jennifer Parker Ainsworth*____________

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ATTORNEYS FOR DEFENDANT
MARVELL SEMICONDUCTOR, INC.

CERTIFICATE OF SERVICE

The undersigned certifies that the foregoing document was filed electronically in compliance with Local Rule CV-5(a). As such, this motion was served on all counsel who have consented to electronic service, Local Rule CV-5(a)(3)(A), on this the 25th day of January, 2008.

*/s/ Jennifer P. Ainsworth*_______

Jennifer P. Ainsworth